NUCLEONICS

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October 1954

Largest U. S. Open-Pit URANIUM MINE

PAGE 47

How to select the right **vapor pump fluid**

The only "moving part" in your *high vacuum* diffusion or oil ejector pump is the fluid continuously cycling between the liquid and gaseous phases.

The kind and quality of this fluid largely determine the efficiency of the pump.

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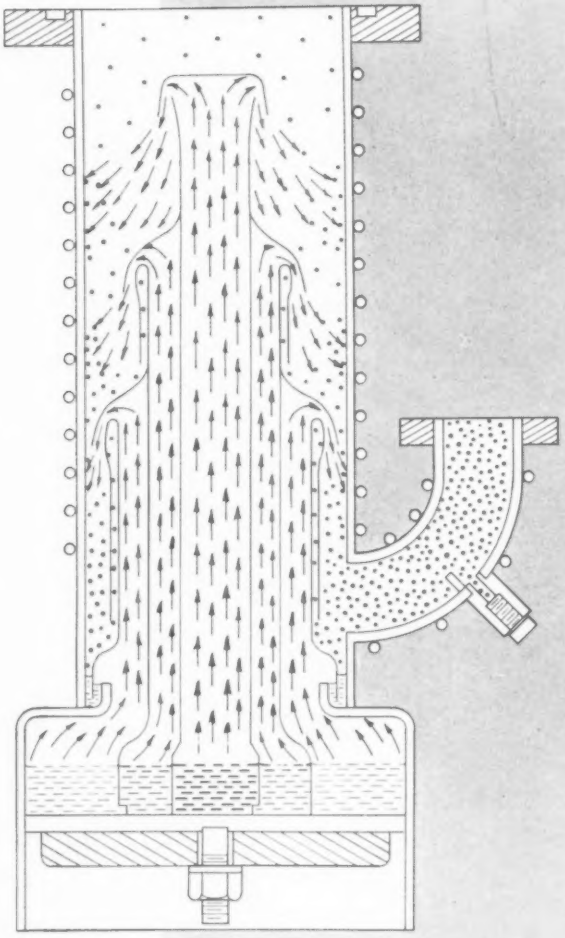

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OCTOBER • 1954

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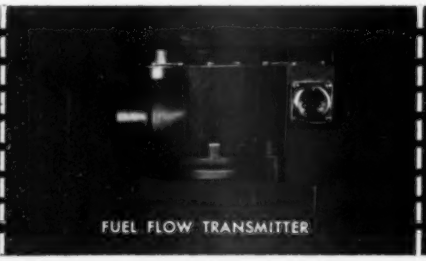

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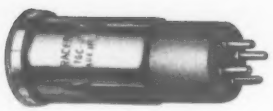

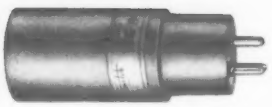

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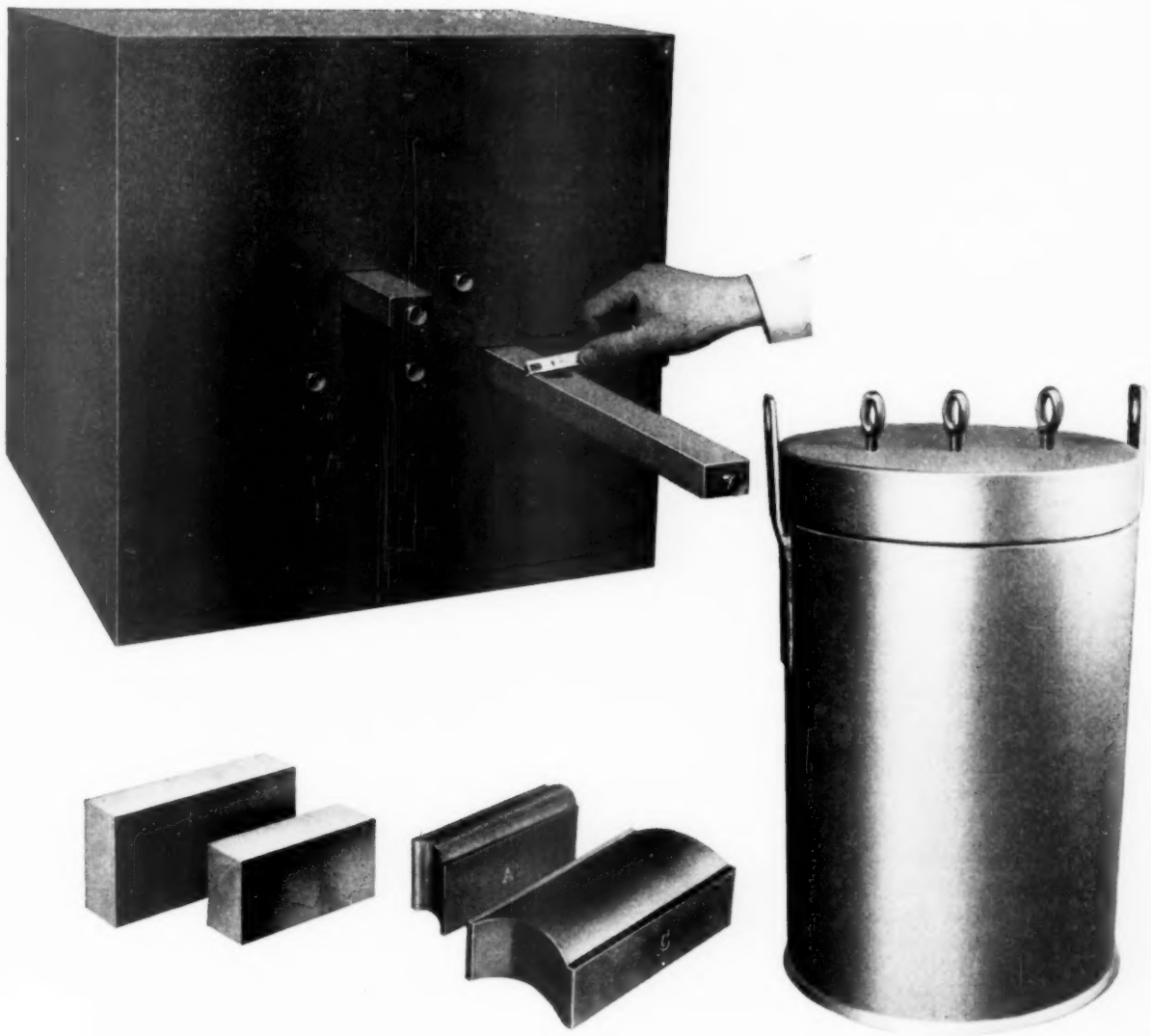

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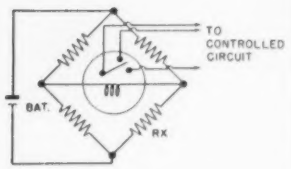
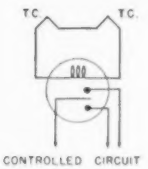


Resistance Selection



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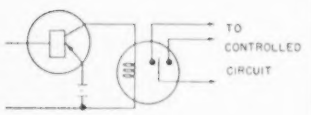
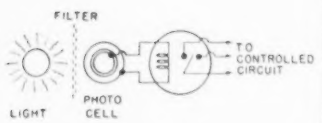


Transitor Selection



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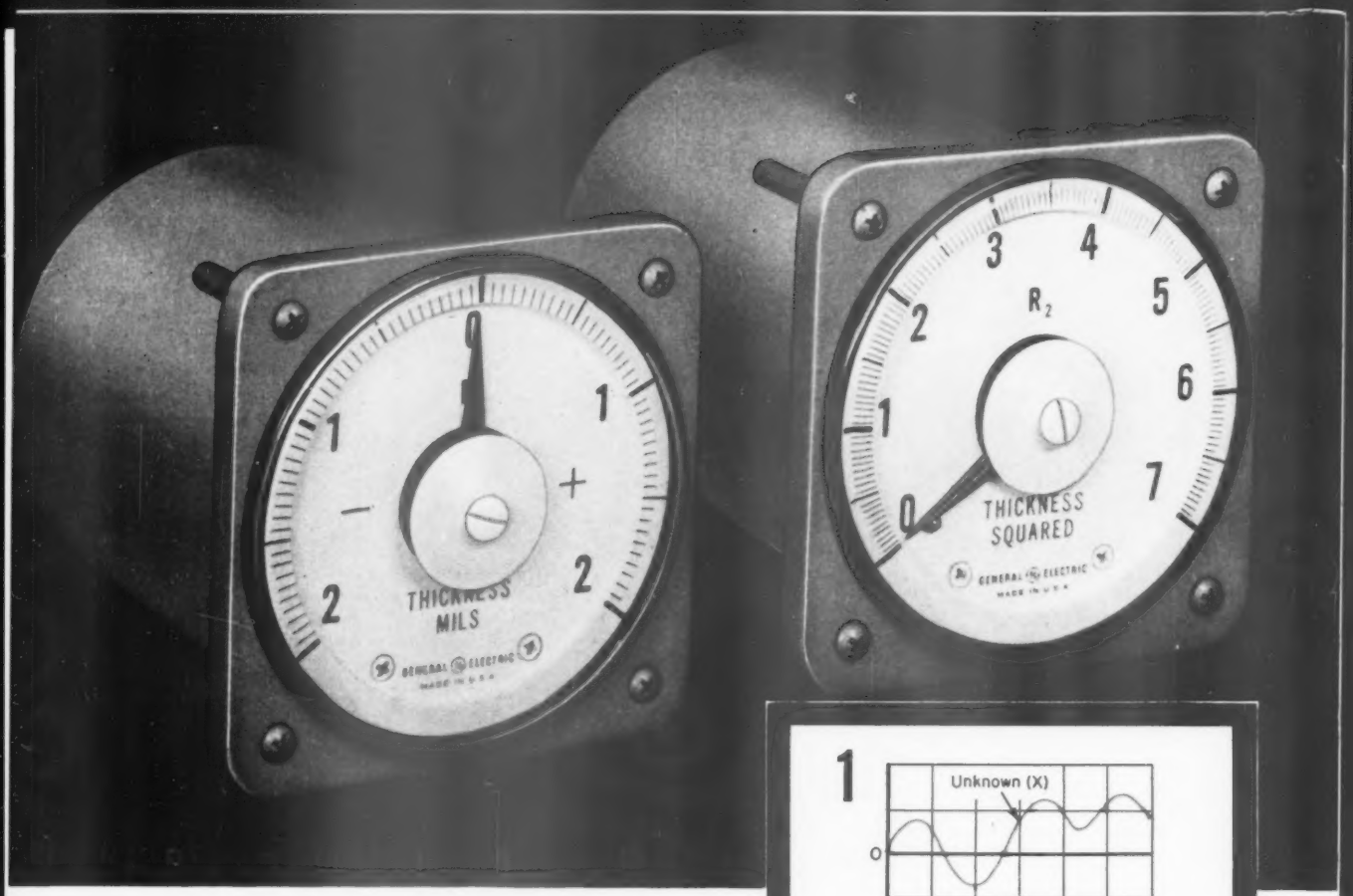

General Electric Announces . . .

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...To provide a quick and simple means of determining the mathematical integral of a varying unknown — or of the integral of the unknown-squared.

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FOR FURTHER INFORMATION, contact your nearest G-E Apparatus Sales Office, or write for Bulletin GEC-1230 to: Section 605-80, General Electric Co., Schenectady, N. Y.

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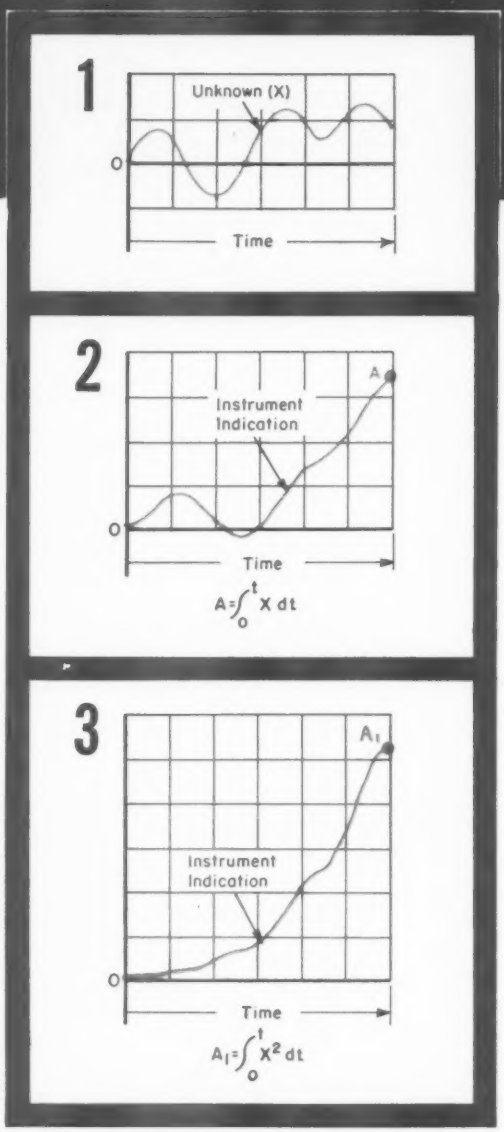

LATE NEWS and COMMENTARY

Legislative and business problems facing the nuclear industry under the new atomic energy law were thrashed out at a meeting of the Atomic Industrial Forum, September 27 and 28. Below are highlights of the Forum meeting. (Details of industrial planning under the new law as reported at the meeting will be published in the next issue.)

•

Analysis of Law Aspects of new law favorable to development of nuclear industry: nuclear fuel available for commercial use; industry can own and operate reactors; AEC must buy back from industry new fuel that is regenerated; AEC is authorized to reprocess used fuel; electric energy produced in nuclear plants can be handled in normal way; production and distribution of source materials remains in private hands.

Here is what a private utility will need from AEC to be able to build and operate a nuclear power plant:

- —initial allotment of fuel to load reactor, and a "working" excess
- —assurance of future firm supply of fuel
- —contractual commitment on reprocessing of fuel
- —license permitting receipt, possession and transfer of fissionable material
- —license for possession and use of byproduct materials
- —licenses for construction and operation of plant. Automatic licensing for operation does not necessarily follow completion of construction.

Most serious deterrents to industry, according to one speaker, are severity of license revocation provisions and limitations on long-term fuel commitments.

There are two basic kinds of plant licenses: for "commercial" plants (Sec. 103) and for "research" plants (Sec. 104). Differences between the two are fuzzy. A minimum of regulations is to be applied to 104 licensees. They will get greater assistance from AEC (e.g., they can get free use of fuel). Before any 103 license is issued, AEC must advise Attorney General regarding anti-trust possibility. AEC must charge for fuel under 103 and must make additional special charge for fuel that is consumed.

AEC will control nuclear facilities (production and utilization) and materials (source, byproduct and special). AEC has power to determine what level of production of plutonium makes a facility a production plant. A utilization facility can be broadly interpreted and may not be limited to reactors. Under materials controls, AEC can add new ones to list of special nuclear materials and force sale by industry to AEC.

Seven-year guarantee by AEC to purchase industry-produced fissionable material starts from date of agreement with licensee on price rather than from date of completion of plant.

•

Patents On patents, Sec. 152 on inventions conceived during AEC contracts may create greatest problems. One AEC spokesman said, "Overwhelming knowledge is now in Government labs, and it would be very difficult for a company to prove its originality. This will be watched closely by AEC." Another speaker said, "This section has introduced hazards and uncertainties of real magnitude."

AEC can require compulsory licensing of patents on own initiative or on that of an outsider. In former case, AEC must find the invention to be of "primary importance" in the industry and in an applicant's activities. In the latter case,

AEC must additionally find the applicant's activities of "primary importance" to furtherance of policies and purposes of the Act.

•

Information Policy Bolder declassification policy is implied in new law. Significant change is that now AEC can declassify if there is no "undue risk" to common defense and security rather than that such declassification would not "adversely affect" common defense and security. Now those wishing to keep things classified, rather than reverse, must justify their position. So-called "gray area" of classification (that which contains relatively nonsensitive information) can be significant to industry if not used as substitute for declassification.

•

Power of Congress Role of Joint Committee on Atomic Energy has been emphasized and increased with following responsibilities: approval of AEC designation of new materials as special nuclear materials and as source materials; approval of agreements for international cooperation; control of AEC expenditures on plant construction or expansion; and continuing studies of AEC and the atomic energy industry. Special hearings to be held each year. This was called "greatest function" of JCAE in next few years.

•

Fuel Supplies Availability of uranium will determine speed of development of nuclear power industry. AEC pushing of industry presumes adequate supplies for any conceivable growth. President must make determination each year of amount available for industry. Preference clauses related to licensing (preferences to public power groups, high-cost power areas, groups with "best" plant designs) are presumably academic unless there is shortage of nuclear fuel.

•

Insurance Needs Inadequate insurance coverage is available for industrial nuclear power plants. One industry guess is that ceiling would be $3-million domestically and $10-million abroad. An insurance executive recommended (1) that atomic industry determine its insurance needs in type and quantity and (2) that insurance industry set up cooperative program for writing maximum insurance. If there's spread between (1) and (2), atomic industry or Government should sustain balance of risk, he feels.

•

AEC Advice Time has passed when industry can come to AEC to get large contracts for purpose of learning the business said L. R. Hafstad, AEC reactor chief. He also said:

"We've been talking about reactors for three years in the study programs. If industry was as aggressive as it should be, why hasn't anyone come up with a plan to take advantage of the new law? We need action now. We need aggressiveness if we are to compete with European nations.

"Equipment suppliers and utilities say they're ready, but nothing happens. Each is waiting for the other.

"It's prudent for industrial magnates to protect stockholders against losses. If there's anything at all to atomic energy, let's not piddle. Let's learn fast what the future holds.

"Utilities should decide whether to sit back and wait for the Government to develop competitive plants. If they do this, we'd then have giveaway charges."

Hafstad gave this advice: To equipment suppliers—"Do a sales job—on such things as research reactors, fuel elements, etc." He suggested that industry, not the Government, should build a fuel-element testing reactor. To utilities—submit serious "reactor of the year" proposals to AEC, whereby industry and AEC would split plant cost.

NUCLEONICS OCTOBER, 1954

Jerome D. Luntz, *Editor*

Make it an Honest Bid

NOVEMBER 19 IS THE DUE DATE for lump-sum bids on the Army Package Power Reactor. Thirty-three industrial organizations are prospective bidders. This is an historic event of great significance to the atomic energy industry and considerable importance will be attached to the selection of the successful bidder.

No reactor has ever been built before on a lump-sum contract, although 32 reactors have been built in this country since 1942. All have been built on a cost or cost-plus basis. All have been directly or indirectly related to the military effort. Time was of the essence with cost a secondary factor.

In addition, little experience was available on the performance of reactor components and materials to warrant anyone's gambling either on the life of a reactor system or on its cost. And so the Government has always sustained the risk although the reactors were engineered and built by industry.

WHAT HAS CHANGED to make this first risk-bid feasible? First, considerable knowhow has been gained on reactors in general. More important, there is experience on this specific kind of reactor—pressurized, highly enriched, light-water moderated and cooled. A similar reactor, the prototype of the STR for the NAUTILUS, has been running in Idaho for the past 18 months, providing invaluable data. Further evidence of the state of development of this reactor type is that the Government selected a pressurized light-water reactor (the PWR being built at Shippingport) for the first industrial nuclear power plant because the most was known about it and it consequently could be built in a relatively short time.

Another factor has been the interest and desire of many companies to make reactors their business, and their realization that it isn't really a business until it is on a fixed price basis.

A third critical factor is the willingness of AEC to allow control of development details to pass from their own hands.

Additional evidence of the feasibility of doing the job on a fixed-price basis is that the one big question mark—the fuel elements—does not seem to be a big one here. It was originally thought that the prime contractor on the APPR would not be responsible for the performance of the fuel, that the onus would be on AEC. This has not turned out to be the case, partly because at least several fabricators of fuel elements will guarantee the six-month life required.

In fact, it appears from the wording of the invitation that AEC is offering industry incentive to do the job. If the contractor prefers, AEC will fabricate the fuel and will add $140,000 to the bidder's figure. Industry will have to beat $140,000; some think it should be easy to do.

Despite the favorable factors present, bidding will be tough. Just the mere fact that this is the first such contract means the bidders will be guinea pigs. Even writing the final contract will be hard.

Although there have been considerable advances in the field, it would be an understatement to say that the job is far from pat technically.

In addition to having to meet stringent safeguards requirements on reactor and building, the contractor's ideas will be subjected to the careful scrutiny of AEC's Advisory Committee on Reactor Safeguards. Because policy changes may be necessary on this job, the contractor must try to avoid becoming the victim of differences in philosophy or approach, although AEC says it will take this into account.

The job is also tough because it requires three kinds of knowhow—nuclear, power conversion, and construction. Many of the bidders, with background in only one of the three, are teaming up with other companies.

IF IT'S A TOUGH JOB, why then is it good for the industry for it to be done on a risk basis? This will be the first nuclear power plant built in the world where cost is such an important factor. Thus, it will be an important first step in the development of the nuclear power industry. It will make people cost conscious in an industry where it hasn't been important. It will be a dramatic demonstration of the serious interest of industry in this field. It will give industry a clearer picture of the problems involved in selling nuclear power plants.

It is vital that the bidding and the selection of the bidder be undertaken with this background in mind. This job will show the Government and other prospective customers what they can expect from industry.

We estimate that anywhere from $\$1/4$–$1/2$ million will be spent by the bidders on preparing their bids. It is obvious that some very serious thinking and engineering is being done by many of them. For various reasons—toughness of job specs, lack of real interest, etc.—not all of the 33 invitees will submit bids. And there are some companies that did not express interest in getting an invitation because they felt some of the bidders might try to "buy" the job with an unrealistically low bid.

Because of the importance of this first job, we think it would be very unfortunate if the job were "bought." The responsibility that this doesn't happen is on the shoulders of industry and the Government—industry to keep in mind the long-term development of the field, and the Government (within legal bounds) to see to it that the award goes to a responsible company with experience in this field and one that submits a realistic bid.

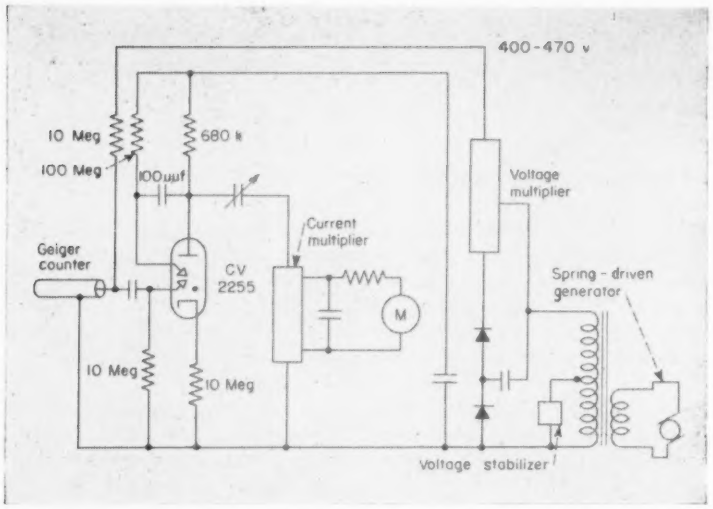

FIG. 1. Survey meter using spring-driven electric generator. Power requirements tubes, 0–3 mw; Geiger counter, 0–2 mw; stabilizer, 1 mw minimum

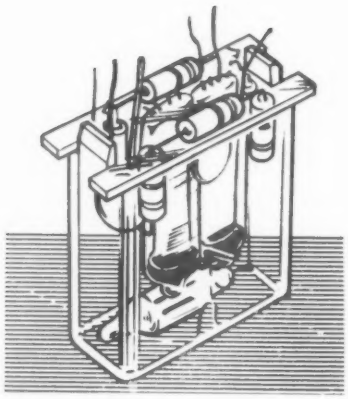

FIG. 2. Miniature scale-of-two using subminiature pentodes

Trends in Nuclear Instrumentation

New, more portable survey meters; novel pulse-height analyzers; scintillation counting; air-monitoring equipment of increased sensitivity; transistor circuitry; and reactor instrumentation are reported here

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THE PURPOSE of the Instrumentation Conference was to exchange information on new circuits, techniques and instruments developed in the American, British and Canadian atomic energy projects. The conference was held at Harwell, England during the week beginning May 3, 1954. This report, prepared at NUCLEONICS' request, describes the highlights of the meeting.

Instrument Reliability

There was much discussion at the meeting about the reliability of nucleonic instruments and statistics of reliability were presented from American, Canadian and British sources. In most respects experiences in the three countries have been similar.

In the case of the standard laboratory nuclear units: scalers, power units, amplifiers, etc.; the fault rate was given as about 0.5 to 1.5 faults per year according to type. Thus, for simple assemblies of units the total fault rate can be sufficiently small to be of little consequence. However, for elaborate assemblies involving many units the operating time per instrument failure can be seriously short. Any failures in the operation of plant instruments (e.g., instruments associated with nuclear reactors, or with radiochemical plants) are liable to result in a hazard as well as loss of valuable operating time.

It was noted that the special components like Geiger counters and photomultiplier tubes had good reliability records, while more orthodox components like vacuum tubes and resistors had the highest failure rates. Vacuum tubes accounted for about 70% of all failures. In general, the American and Canadian resistor failure rate was lower than the British. Part of the improved Canadian performance was probably due to their policy of de-rating all resistors 50%.

Failure rates for vacuum tubes were

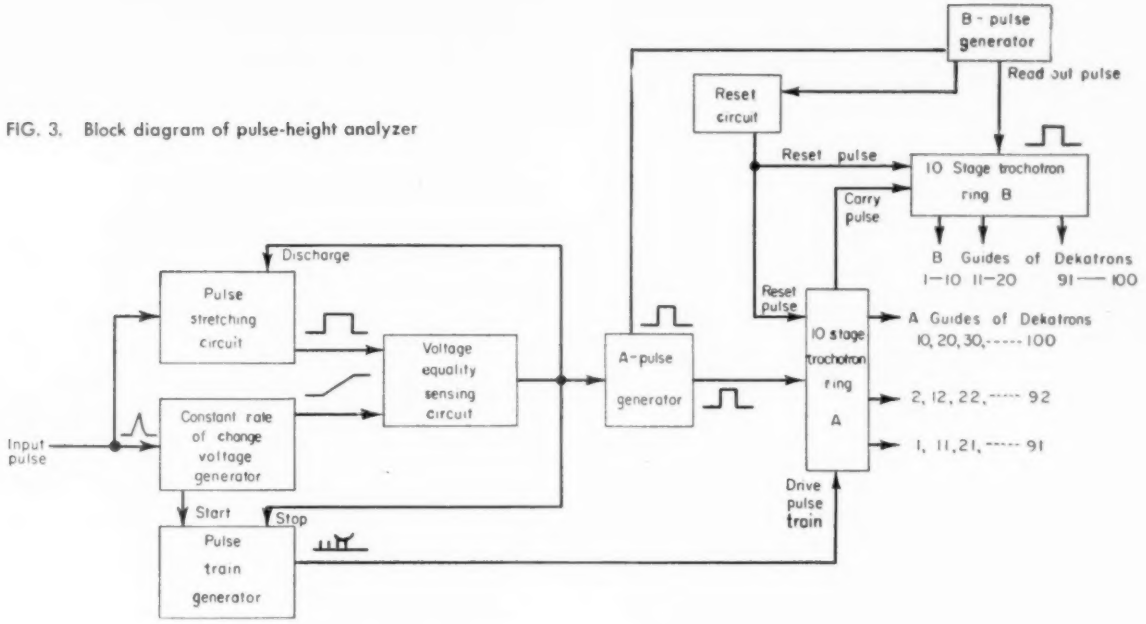

FIG. 3. Block diagram of pulse-height analyzer

much the same in the three countries with rectifier tubes the worst offenders. Dry disk rectifiers are in large-scale use in British nuclear instruments with low failure rates (about 0.4% per annum as compared with about 6% per annum for rectifier tubes). Experience in Canada and America with selenium rectifiers has not been so satisfactory.

Many examples of nuclear instruments with inadequate ventilation were presented. It seems that many instrument designers still need to be reminded of the need for heat removal if reasonable reliability of a large assembly of nuclear units is to be obtained. In general, it was possible to find a satisfactory reason to account for any very high or very low incidence of failure, and usually these reasons involved the adequacy or inadequacy of heat removal.

Several of those attending the conference attempted to use the statistics presented to lay down guiding principles to follow when designing complete nuclear instruments. Thus, it was noted that the failures in power rectifier tubes and stabilizers were out of all proportion to the number of components involved. Therefore a common power supply for all units of multi-unit equipment is indicated, since failure of any one unit is equivalent to the failure of all.

In the early days of the atomic energy projects standard subassemblies were used in varying combinations for different purposes. With the need for the highest reliability, the modern tendency is to design a complete instrument for each particular job. Consistent with satisfactory performance, the minimum number of components, of lowest possible nuisance value, are used; this is particularly so in the case of instruments designed for industry.

All three countries reported increasing use of decade scaling tubes. Increased reliability was obtained by using these gas-filled counting tubes.

The causes of component failure were discussed. Information was presented from American sources that ⅓ of tube-induced failures were caused by slow changes in the characteristics that eventually resulted in catastrophic failure of the equipment. The principle of marginal testing, where the equipment is subjected to changes in currents and voltages that narrow the margin of safety, will prevent the failure of equipment in use due to such slow drifts.

In the majority of instruments the effects of drifts in components and tubes is equivalent to a change in the supply voltage. Hence, the use of common power supplies facilitates the marginal testing of complex equipment. Tests of this type seem likely to be used increasingly; already laboratory nucleonic instruments with marginal testing facilities are becoming available (*1*).

Portable Instruments

The use of cold-cathode tubes in radiation-monitoring apparatus was discussed, and **F. Goulding** (Atomic Energy of Canada, Ltd.) described a contamination meter using such tubes. It is a light-weight instrument for monitoring γ-radiation over a range 0.1–50 mr/hr. It uses a spring-driven vibrator power unit to chop the voltage of a dry cell. The vibrator runs for 50 min on one wind. It uses two cold-cathode tubes, one in the voltage-stabilizing circuit and the other in the counting-rate-meter circuit. The power consumption for the complete instrument is only 20 mw, which allows 200 hr of life from a 1.5-v cell.

Hardwick also discussed the use of cold-cathode tubes in installed health-monitoring apparatus, and he described a further development of the preceding circuit in which an alarm and a pen recorder are used. To provide an alarm a "Sensitact" meter-type relay with full-scale sensitivity of 40 μa is placed in series with the output meter.

The relay can be preset to make contact anywhere in its range. A current differential of less than 1 μa produces a positive contact, thereby

operating a standard 1.5-ma relay in the circuit.

If continuous recording is required, a magnetic amplifier is used to amplify the 50 μa to 1 ma. The functions of alarming and indicating are carried out with a total power consumption of 35 mw; a large number of these monitors can be used without excessive power requirements.

Franklin (AERE), proposed eliminating batteries in portable survey meters by reducing the total power requirements to the order of a few mw and replacing the battery by a spring-driven generator (*2*). Such generators are small and operate for several hours on one wind. Batteryless survey meters of this type have important application in field surveys and radiological defense.

A circuit for a field survey meter using a spring-driven generator is shown in Fig. 1. One cold-cathode tube is used in the counting-rate-meter circuit and, to economize still further in power supplies, a pulse transformer is employed as a current multiplier. The spring-driven electric generator is stabilized electronically and a Cockcroft-Walton voltage-multiplier circuit is used for the Geiger counter high-voltage supply.

Scaling Circuits

Scaling circuits received a great deal of attention. Discussion ranged from Dekatron scalers to scalers using subminiature tubes and transistors. An interesting miniature scale-of-two developed at Oak Ridge is shown in Fig. 2. This uses subminiature screen-grid triggered pentodes. The resolving time is approximately 4 μsec. The total power required for one unit is 220 mw. An automatic preset-count scale of 4,096 has been built using this basic circuit. It consists of a voltage discriminator, twelve scaling stages, start-stop gate and a precision electronic gate with mechanical register indication. The resolving time for random pulses is about 8 μsec, and the total power consumption of the unit is 12.5 w.

Pulse-Height Analyzers

The Scarrott kicksorter (*3*) involving an amplitude-to-time conversion was discussed, and it was noted that kicksorters of this type are now being used on both sides of the Atlantic. Most users find the cathode-ray-tube display useful in providing a quick indication of changes necessary in the experiment or instrumental faults, but the binary scales render difficult the extraction of information from the tube.

A number of devices have been designed for making this task easier. The AERE version of this kicksorter, for example, is to be fitted with a pulse generator feeding negative pulses into a channel of the cathode-ray-tube display until its count is reduced to zero. The count is given by a 5-decade Dekatron scaler into which the negative pulses are also fed.

C. J. Borkowski (Oak Ridge National Laboratory) pointed out that conventional multi-channel pulse analyzers are subject to drifts in channel widths due to relative variations in the channel boundaries. He described a new system, using a beam-deflection tube, in which channel positions depend on mechanical tolerances of a grid system (*4*).

O. R. Frisch (Cambridge University) suggested that this analyzer might be adapted to operate as a two-dimensional pulse analyzer in connection with meson studies.

J. B. H. Kuper (Brookhaven) described a fast 10-channel pulse analyzer built for use with a Cerenkov counter at the Cosmotron. Counter pulses are shaped by a shorted line, amplified by a fast linear amplifier, and applied to the deflection plates of a DuMont K1059 cathode-ray beam-deflection analyzer tube. The rise time for this system is 2×10^{-8} sec; pulse width is about 0.05 μsec to avoid pile-up at high counting rates. Fast coincidence signals from a counter telescope select the pulses to be analyzed by gating the analyzer beam. The intensifier pulse lasts less than 2×10^{-8} sec. Pulses from each of the 10 channels in the analyzer tube are amplified and fed to a stable, low-level discriminator. The channel resolution is about 1 μsec. For each count a quantized charge is fed to a storage capacitor. A feedback electrometer circuit drives a panel meter indicating capacitor voltage. Drift of the accumulator circuits is less than 1% of full-scale reading per hour in operation.

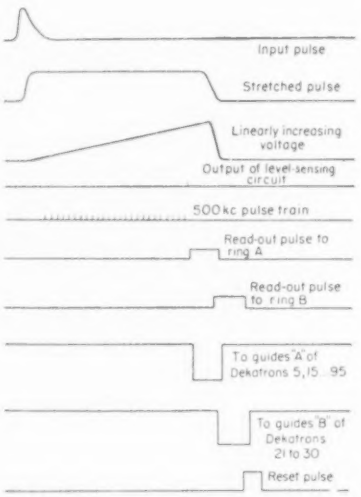
Input pulse
Stretched pulse
Linearly increasing voltage
Output of level-sensing circuit
500kc pulse train
Read-out pulse to ring A
Read-out pulse to ring B
To guides 'A' of Dekatrons 5,15...95
To guides 'B' of Dekatrons 21 to 30
Reset pulse

FIG. 4. Waveforms for pulse analyzer of Fig. 3. Pulse falls in channel 25

K. Kandiah (AERE) described an interesting development of the Wilkinson (*5*) kicksorter. A basic part of the Wilkinson system is a ring of m and a ring of n with their outputs connected in a matrix. Every complete circulation in the ring of m moves the ring of n one stage. Combined with other appropriate circuitry an mn-channel analyzer can be constructed.

The present system, described in more detail elsewhere (*6*), has a 500 μsec resolving time. It uses trochotrons in place of the ring counters, and uses GC10B Dekatrons to perform the combined functions of coincidence unit and digital counter for each channel. The block schematic of the new 100-channel analyzer is shown in Fig. 3; pertinent waveforms are in Fig. 4. The waveforms refer to a signal pulse falling in channel 25.

The pulse is stretched with the usual diode-capacitor arrangement. A linearly increasing voltage and a 500-kc pulse train start simultaneously. The pulse train is fed to ring A, and the carry pulse from ring A is fed to ring B. When the sawtooth voltage reaches the voltage stored on the capacitor, the level-sensing circuits stops the pulse train.

Immediately after this a read-out pulse of about 100 μsec duration is fed to ring A. In turn, negative transfer pulses of about 120 volts are applied to the A guides of Dekatrons 5, 15 . . . 95 since ring A is stopped on position 5. After the A read-out pulse ends, a similar pulse is applied to ring B, which will therefore apply a negative transfer pulse to the B guides of Dekatrons 21 to 30. Since Dekatron 25 alone received both transfer pulses, it alone will advance one digit.

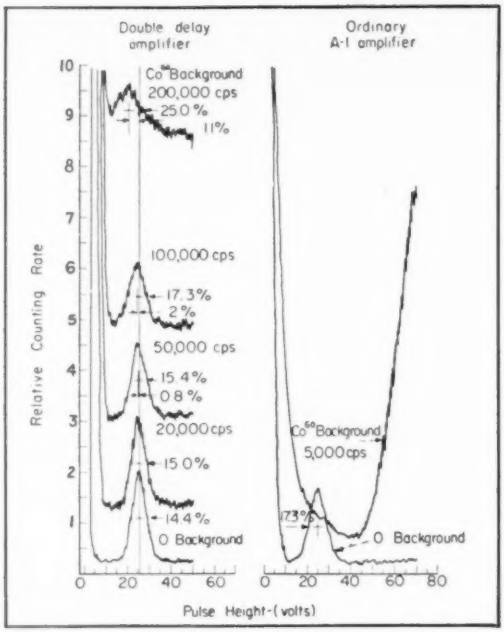

FIG. 5. Comparing the overload characteristics of ordinary and double-delay amplifiers

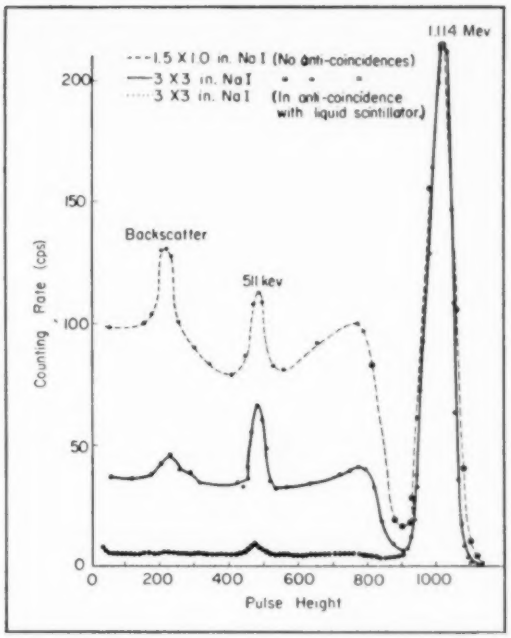
1.114 Mev
1.5 X 1.0 in. NaI (No anti-coincidences)
3 X 3 in. NaI
3 X 3 in. NaI (In anti-coincidence with liquid scintillator)
Backscatter
511 kev
Counting Rate (cps)
Pulse Height

FIG. 6. Zn^{65} spectrum, illustrating the improvement in photopeak resolution using P. R. Bell's anti-coincidence method

At the end of the *B* pulse a positive reset pulse is applied to reset the trochotrons used for the two rings-of-10.

In a complete analyzer it is necessary to have certain ancillary circuits to avoid errors. It will be appreciated that in the system described above, a pulse higher than the highest channel would be counted in one of the channels as a pulse of lesser amplitude. It is therefore necessary to have a circuit that shunts all pulses higher than a certain value to a special channel. It is also necessary to introduce a gate that prevents pulses from entering the stretching circuits while a previous pulse is being analyzed.

This new kicksorter is simpler and uses fewer tubes and components than many in use. Mr. Kandiah expressed the opinion that many of these new kicksorters would be in use in the near future.

Pulse Amplifiers

Nonlinear amplification at high pulse rates implies poor resolution of small pulse-height-distribution peaks in the presence of high background. J. E. Francis, P. R. Bell and G. G. Kelley developed a double-delay-line amplifier that solves this problem in good part (7). **Borkowski** (Oak Ridge) gave some hitherto unpublished performance figures for that amplifier that are shown in Fig. 5. They amplified a 2,000 cps, 0.032 Mev, Ba X-ray peak from a Cs^{137} source, against a Co^{60} background that ranged from 0 to 200,000 cps. The X-ray peak is lost when a conventional amplifier is subjected to 5,000 cps background. The peak is still recognizable, using the new amplifier, at 40 times that background rate.

Photomultipliers, Scintillators

R. L. Butenhoff (AEC) reviewed American photomultiplier tubes, particularly the large-area tubes now being made by DuMont. Tubes suitable for fast timing experiments were discussed; there was a preference for the RCA 6347 2-in. tube, which has a transit spread between 4 and 5×10^{-12} sec. **R. B. Owen** (AERE) gave a review of EMI tubes and referred to the new 6099 photomultiplier. This has a 4½-in. photocathode mounted in a 5-in.-diameter envelope.

An interesting application of the 5-in. tube is floor monitoring. The tube views a 24-in.-diameter phosphor screen located within an inverted ash can on wheels. When the can is lowered onto the floor, a light seal is made around the rim with a partially inflated rubber cycle tube. The phosphor is covered with 0.0002-in aluminium (not necessarily light-tight) to prevent errors due to differing reflectivities of the floors to be monitored and to prevent excessive excitation of the phosphor by room light when it is moved.

Equipment of this type has been in use at the AERE for a few months with very satisfactory results. The variation in sensitivity across the 24-in. diameter is less than $\pm 10\%$, and the equipment can still be used after the foil develops gross holes.

On the more academic side, some results obtained by P. R. Bell (Oak Ridge) were reported. In these experiments Bell used a 5-in.-diameter photomultiplier tube and attempted to obtain a single photopeak from γ-rays by reducing the Compton contribution. He used a 3×3 in. NaI crystal surrounded by a large-volume tank of liquid scintillator (xylene) scanned by two photomultiplier tubes at top and at bottom. The source was placed on the crystal and pulses common to crystal and liquid were rejected from the pulse-amplitude analyzer by an anticoincidence system, so that de-

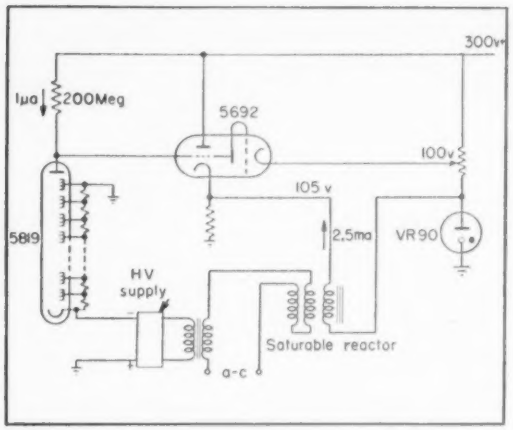

FIG. 7. Wide-range scintillation-counter monitor

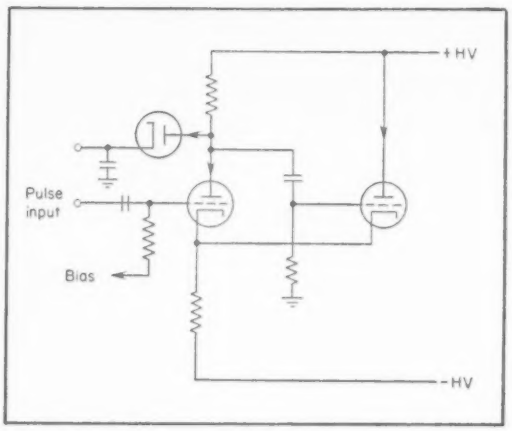

FIG. 8. New sensitive discriminator circuit

graded γ-rays were eliminated. The results are given in Fig. 6 for Zn^{65} γ-rays.

Several novel scintillation-counter circuits were discussed. Only one, reported by **Hardwick,** will be mentioned here. It makes use of the relation between photomultiplier sensitivity and dynode voltage to produce a wide-range quasi-logarithmic dose-rate meter. Previous circuits have suffered either from complexity, or from operating tubes at excessive voltages.

The new circuit is shown in Fig. 7. It employs a double-triode; one section is used as a cathode follower and the other as a diode. Control of photomultiplier voltage is accomplished by putting the output of the cathode follower through the control winding of a saturable core in series with the high-voltage transformer primary.

With a 5819 photomultiplier and a plastic phosphor 1½ in. in diameter by 2 in. thick, radiation levels from less than 0.01 r/hr to more than 100 r/hr could be measured.

Radiochemical Instrumentation

The discussions on chemical instrumentation ranged from apparatus in use in the laboratory to actual plant instruments. It was noted that most laboratory α-counting is still carried out with conventional flow counters* and that scintillation counters are rarely used for such measurements. On the other hand, the advent of the scintillation counter has caused more emphasis to be placed on the γ-activity associated with most fission products and β-counting is little used.

One popular component is the 2-in.-diameter NaI crystal with a ½-in. re-entrant hole. This provides good geometry, although the presence of the hole reduces the resolution by a factor of about 2. However, the counting rate can be almost independent of sample volume over wide limits, and the over-all counting yield may be 20–50% or higher depending on the γ-ray energy.

H. Bisby (AERE) gave an account of some more specialized measuring instruments. Difficulty sometimes arises in monitoring α-rays directly because they are absorbed in the walls of the containing vessel. Bisby pointed out that it was sometimes possible to take advantage of a secondary process. For example, plutonium α-rays striking nitrogen or fluorine atoms cause neutrons to be produced by (α,n) reactions. These high-energy neutrons will be moderated if the material is in the form of an aqueous solution. The neutron energy and flux measured externally depend on chamber size and other factors as well as the amount of α-active material. Nevertheless, this approach to the problem is a useful one, and Bisby gave some examples of the use of this method.

Particulate α-Activity

The standard instruments for measurement of particulate α-activity suck the affected air through filter paper for a measured time (usually a few hours), after which the paper is removed and examined for activity. The time lag has proved a serious disadvantage, and development has been towards decreasing this by continuous monitoring of the activity.

Two instruments were discussed at the meeting, one to give a quick indication of high activity and the other to give a slower indication of medium levels of activity. Both use continuously moving filter paper drawn past a sucking aperture and then under a scintillation α-counter. The form of apparatus used by AERE differed only slightly from that described by J. B. H. Kuper (*8*). The filter paper takes 10 min to cross the sucking aperture, sampling 3 cubic meters of air in this time. The transit time between aperture and scintillation counter is variable. With minimum delay, the geometry is such that 2.7 cpm corresponds to 1 mpl (maximum permissible level) for Pu α-particles.

Under normal weather conditions at Harwell, the counting rate produced by the natural radon and thorium in air varies from 20 to 200 cpm (midday to midnight). Under exceptional conditions of temperature inversions at midnight, this background is 300 cpm, corresponding to 100 mpl. This is probably typical of many localities. Thus the warning system cannot be left unattended set at less than 100 mpl.

The second type of instrument, to measure medium levels of activity, uses a two-channel system. One channel measures the radon activity in the air,

* Methane gas is used in North America, but argon is used in Britain, largely because methane gas of adequate purity is not easily available.

the other this plus any laboratory contamination. The difference is recorded. A wide strip of filter paper is drawn across the two sucking apertures and then under two scintillation counters.

For 1-mpl accuracy on a background of 100 mpl, the air flow in the two channels must be identical to within ±1%. This, the most difficult part of the problem, is realized in the British instrument by the use of sensitive diaphragm valves in each channel controlling the air flow to a common exhaust fan. **J. F. Hogg** (AERE) said that for a background of 100 mpl, the standard deviation on the output counting-rate meter corresponds to 3 mpl; hence if the alarm is set at 20 mpl, there is a 95% probability of the alarm operating between 14 to 26 mpl.

Hogg mentioned improved models of this two-channel instrument that reduce background by energy discrimination against radon, and that use electrostatic precipitation onto thin aluminium foils monitored between two air proportional counters. It is hoped that this new instrument can be used for monitoring lower levels of activity.

Kuper mentioned the further method of discriminating against background by measuring the α/β ratio; this remains fairly constant for most natural bursts of activity. Thus any increase indicates increased local activity. He also referred to an airborne two-channel contamination meter using electrostatic precipitation.

G. Cowper (Atomic Energy of Canada, Ltd.) said that Pu particles are usually somewhat larger than those of the radon decay products, so that by using a high-speed cascade impactor it is possible to trap only the larger particles.

Circuit Techniques

One of the novel circuit techniques described at the conference was a new type of pulse-amplitude discriminator (*9*) shown in Fig. 7. This will operate at the millivolt level with the same precision as normal discriminators operate at the volt level. The sensitivity can be made completely independent of the d-c stability in any part of the circuit since it relies on a-c parameters of its tubes. Paralysis times of the order of 10 μsec are attainable, and the sensitivity can be in the 1-mv region if a triggering accuracy of ±0.5 mv can be tolerated. For 1% accuracy the trigger level must be about 100 mv. Resolving times of the order of 0.2 μsec are possible if the pentodes are operated at high g_m so that pulse widths as low as 1 μsec can be handled without appreciable change in trigger level. A 50-v output pulse is produced. The triggering sensitivity is calculable knowing g_m and the diode characteristic.

The long- and short-term stabilities of this circuit are excellent. Experience with this discriminator at AERE has shown that it can operate in production equipment with 1% accuracy at the 100-mv level and 15% at 10 mv. It permits great simplification in counting systems, eliminating the high-gain amplifier in most cases. The circuit can be triggered directly from a scintillation counter. For use with a Geiger counter, a modified form provides the necessary quenching pulse. For proportional counters a low-gain amplifier is still necessary.

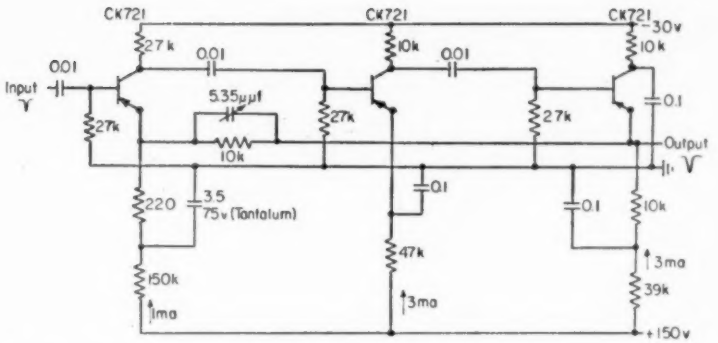

FIG. 9. Ring-of-three transistor amplifier stage

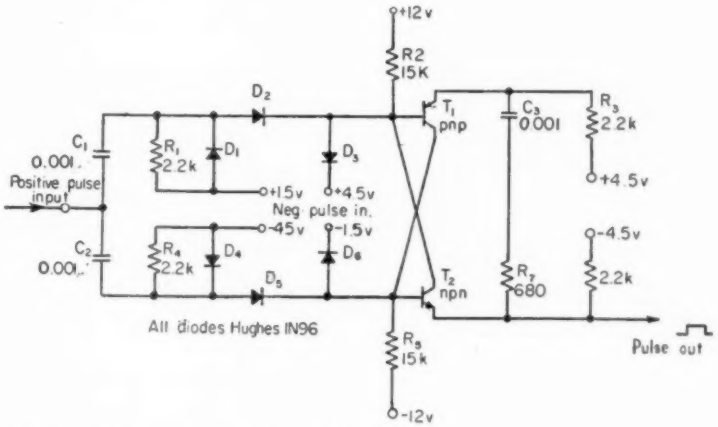

FIG. 10. Scaling circuit using *npn* and *pnp* transistors

Transistor Circuits

There was no general agreement at the conference as to the part transistors would play in future nuclear instrumentation. It was pointed out that the highest resistor values in transistor circuits were about 10,000 ohms. Voltages greater than 20 v were rare. This helps reliability, but transistor temperature sensitivity is a grave disadvantage, and it is not clear what the net gain would be. **E. H. Cooke-Yarborough** (AERE) and **G. B. B. Chaplin** (U.K.) quoted very promising life figures for transistors (*10, 11*).

One interesting development, due to **A. Pearson** (Atomic Energy of Canada, Ltd.), is a thermal-neutron monitor using a proportional counter that produces 350 cps in a thermal-neutron flux of 20,000 n/cm²/sec. A transistor amplifier with a rise time of the order of

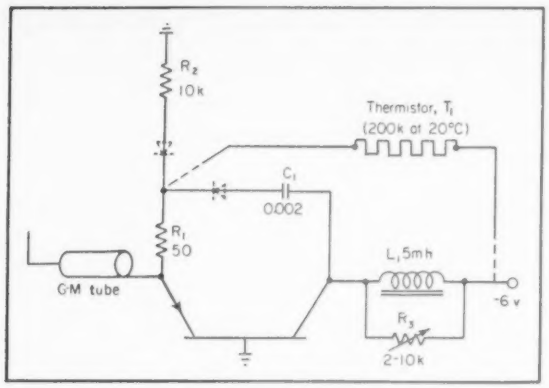

FIG. 11. Trigger circuit using point-contact transistor

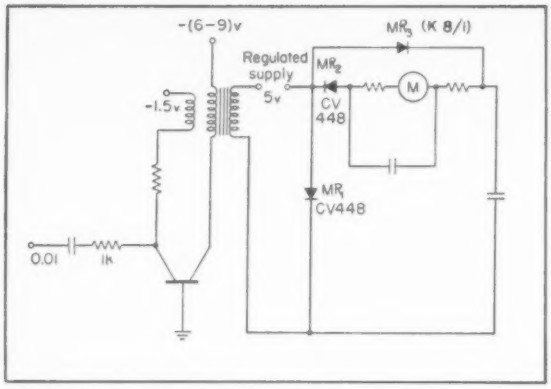

FIG. 12. Transistorized counting-rate meter circuit

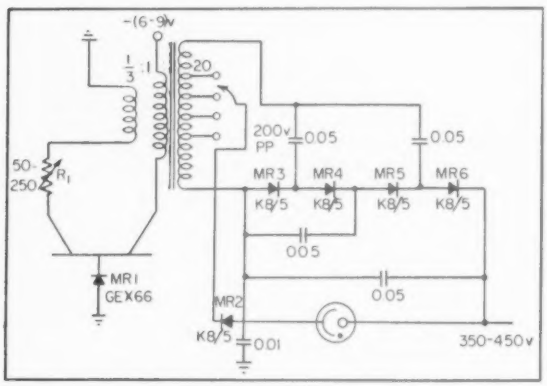

FIG. 13. R. F. power supply employing transistors

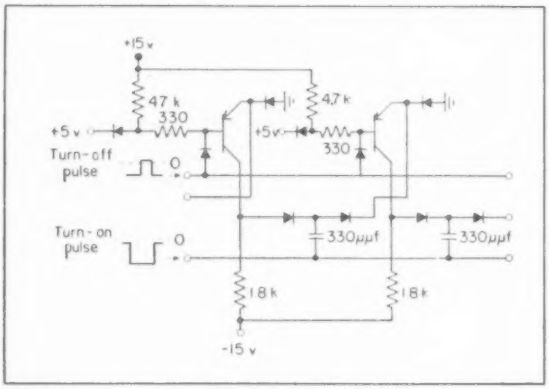

FIG. 14. Two stages of a transistor shift register

3 μsec has been developed to amplify these pulses. It is shown in Fig. 9 and consists of two feed-back rings-of-three in cascade. From the emitter of the output transistor a-c feedback is to the emitter of the input transistor. The d-c operating point for each transistor is stabilized by forcing a constant emitter current from a relatively high voltage supply.

A vacuum tube is used as a cathode follower at the amplifier input. Attempts at using a transistor here in a grounded collector circuit were defeated by the extremely high noise level, presumably due to leakage current flowing through the high input impedance. Transistors are expected to prove more reliable than tubes in this amplifier. As many of these monitors are required in the Canadian project, reliability is important.

F. S. Goulding reported a miniature scaler using junction transistors. The basic circuit, shown in Fig. 10, uses the complementary properties of *pnp* and *npn* transistors. The collectors of T_1 and T_2 are coupled directly to the opposite bases. In the 0 state neither transistor is conducting; in the 1 state both are conducting. The minimum collector current, I_{co}, is about 200 μa at 60° C; excess currents through R_2 and R_5 are taken by diodes D_5 and D_4, and D_3 respectively. The collector current of T_1 supplies the drive current into the base of T_2, R_5 and D_6, which clamps the base at 1.5 volts. Similar circuitry is applied to T_1. As much as 600 μa may be available to flow through D_6 or D_3.

The circuit can be triggered by a positive or negative edge as shown, to obtain reversed outputs from the emitters of T_1 and T_2. The switch over from 0 to 1 occurs when the positive pulse passing through D_6 causes T_2 to conduct. T_2's emitter rises with the input pulse, and this change is fed through C_3 to the emitter of T_1 to bring it into conduction. This is helped by the lowering of the base of T_1 by the i_c of T_2. The current gain (greater than 10) available around the loop produces a rapid switchover to the 1 state.

It seems likely that this circuit, which will tolerate any value of I_{co} and is very uncritical of values of the other transistor characteristics, will find important applications.

A number of these scalers have been constructed using carbon resistors and operated at 20° C and 60° C. The resolving time obtainable was about 5 μsec. A complete scale-of-ten dissipates 20 mw.

Franklin (AERE) gave an interesting account of the development of a portable radiation monitor using point-contact transistors. The point-contact transistors available in Britain from S.T.C. Ltd. have had substantially the same characteristics for the three years they have been avail-

able. Therefore it seemed reasonable to use them in a production monitor. The aim was to produce a monitor that could be used from −40° to +60° C and operate from a small battery or spring-driven generator.

Two points in the design require special consideration: the variation of I_{co} with temperature, and the use of a supply potential that is not high compared with the bottoming potential. The standard trigger circuit, using a base resistor, shows a large variation of triggering sensitivity with temperature due to variations of I_{co}. The situation can be improved by using a base inductor instead of the base resistor.

A better answer is the circuit shown in Fig. 11. The base is now grounded, R_1 is a limiter for the emitter current, and R_2 is a resistor through which C_1 recharges. The inductance L_1 permits good bottoming of the collector, and the time constant, R_1C_1, defines the highest operating counting rate, which for the values given is about 30,000 cps. The shunting of the input impedance by R_2 and the collector circuit can be avoided by the use of diodes as shown. Oscillations on the back edge of the pulses due to the ringing of L_1 can be avoided by choosing L_1, C_1 and R_1 so as to damp the collector voltage critically.

Even with this circuit the triggering sensitivity may vary as much as 5 to 1 with different transistors, due to variations in their V_c, i_e and α, i_e characteristics. The introduction of R_3 makes it possible to adjust the sensitivity so that the circuit will always trigger at greater than 50×10^{-12} coulombs.

This circuit will oscillate at temperatures greater than 50° C, but this can be avoided by using a thermistor, T_1, as shown. This gives increasing negative emitter bias with temperature increase to offset the effect of I_{co} rise. By this means the temperature range has been extended to 60–70° C with all transistors tried so far. The sensitivity is reduced, but a sensitivity of 10^{-10} coulombs is possible by adjusting R_3. The circuit can still be triggered directly from a Geiger tube. Indication is provided by a combination of transistor and diode pump in a counting-rate meter, Fig. 12.

The r-f high-voltage supply for the monitor is shown in Fig. 13. The base diode starts the circuit into oscillation. R_1 is a current limiter for the emitter; if R_1 is less than 50 ohms the transistor will lock on. The efficiency is about 33% at 6 v and could be as high as 60–70% if a junction transistor were used. The circuit can be followed by any conventional rectifier circuit. The limitation on the voltage ratio, here shown as 20:1, is due to stray capacitance across the secondary winding; this should be less than 200 $\mu\mu$f.

Much of the remaining discussion on transistors was on circuits for digital computers and will not be reported here. A shift register circuit shown in Fig. 14 is noteworthy, however. It consists of a string of bistable circuits so arranged that after application of the "turn on" and "turn off" pulses in the proper time sequence, each bistable circuit takes up the previous state of its neighbor on the left, thus shifting the significance of a binary number stored in the register by one binary place.

E. H. Cooke-Yarborough showed how this circuit could be adapted to make a novel scale-of-ten. Four shift stages *a*, *b*, *c* and *d* are connected in a ring, *abcd*. In addition to the normal shift connections from *a* to *b*, *b* to *c*, etc., there is an additional shift connection *d* to *b*, so that if stage *d* is conducting, application of the next shift pulse will cause both *a* and *b* to conduct. As a result the circuit will go through the following sequence (capital letters indicate the conducting stages): *Abcd*, *aBcd*, *abCd*, *abcD*, *ABcd*, *aBCd*, *abCD*, *ABcD*, *ABCd*, *aBCD*, *ABCD*. The *ABCD* condition is arranged to be unstable and resets to the *Abcd* condition.

A scaler using this principle was demonstrated at the meeting. Filament-type indicating lamps were lit directly from the collector currents of the conducting transistors, and an additional point-contact transistor operated an electromechanical register.

Reactor Instrumentation

The discussion on reactor instrumentation covered a wide field. Typical is the automatic start-up equipment developed by **R. J. Cox** (AERE). In this system a signal from a reactor period meter and from a power-level meter are fed into the control-rod servo system. The neutron power builds up with a demanded doubling time and then levels off to a demanded power level. The power setting is then increased uniformly to bring the reactor temperature up to operating level at a constant rate. The system is shown schematically in Fig. 15.

A new type of logarithmic d-c amplifier and period meter is included in this system. It covers a current range of up to 8 decades.

* * *

I am indebted to L. A. Kilbey, Secretary of the Tripartite Conference, who placed all the Conference Papers at my disposal. Messrs. Bisby, Cox and Kandiah also helped greatly. Most of the original contributions given here will be published in greater detail elsewhere by the individual contributors.

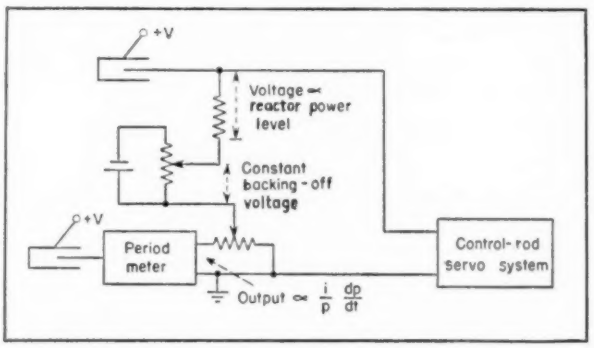

FIG. 15. Automatic reactor start-up control system

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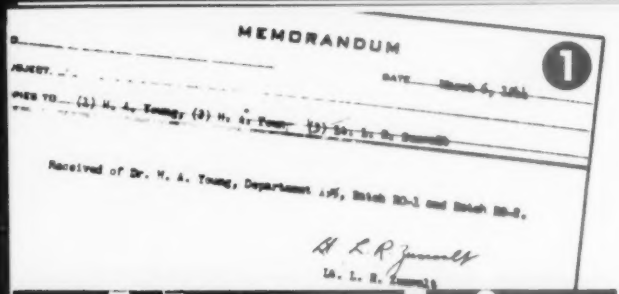
Atomic Archives:

When Uranium Was "Tuballoy"

Exactly 17 months elapsed between the first production of a significant amount of enriched uranium and the dropping of the atomic bomb over Hiroshima. It was on March 6, 1944, that *x* grams of enriched tuballoy (code name for uranium) was sent from Oak Ridge to Los Alamos to be used in a water-boiler reactor for neutron studies related to the bomb. And it was on Aug. 6, 1945, that "a projectile unit containing *x* kilograms of enriched tuballoy" was "expended to Hiroshima."

The documents on these pages, published for the first time, tell the story of this historic period.



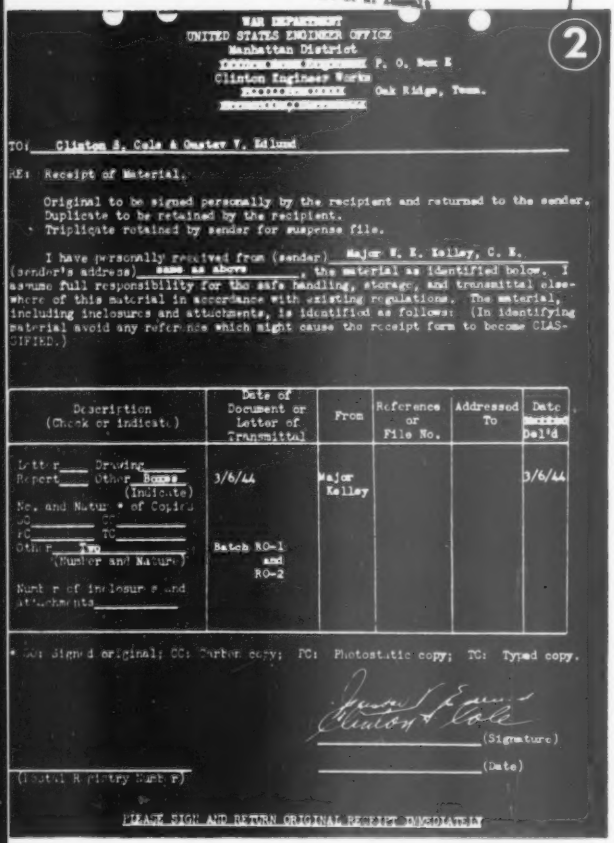
MEMORANDUM

DATE March 6, 1944

Received of Dr. H. A. Young, Department 195, Batch RO-1 and Batch RO-2.

Lt. L. R. Zumwalt

1



WAR DEPARTMENT
UNITED STATES ENGINEER OFFICE
Manhattan District
P. O. Box X
Clinton Engineer Works
Oak Ridge, Tenn.

TO: Clinton S. Cole & Gustav V. Edlund

RE: Receipt of Material.

Original to be signed personally by the recipient and returned to the sender.
Duplicate to be retained by the recipient.
Triplicate retained by sender for suspense file.

I have personally received from (sender) Major W. E. Kelley, C. E. (sender's address) same as above, the material as identified below. I assume full responsibility for the safe handling, storage, and transmittal elsewhere of this material in accordance with existing regulations. The material, including inclosures and attachments, is identified as follows: (In identifying material avoid any reference which might cause the receipt form to become CLASSIFIED.)

Description (Check or indicate)	Date of Document or Letter of Transmittal	From	Reference or File No.	Addressed To	Date Rec'd Del'd
Letter___ Drawing___ Report___ Other Boxes (Indicate) No. and Nature of Copies SO___ CC___ PC___ TC___ Other Two (Number and Nature) Number of inclosures and attachments___	3/6/44 Batch RO-1 and RO-2	Major Kelley			3/6/44

* SO: Signed original; CC: Carbon copy; PC: Photostatic copy; TC: Typed copy.

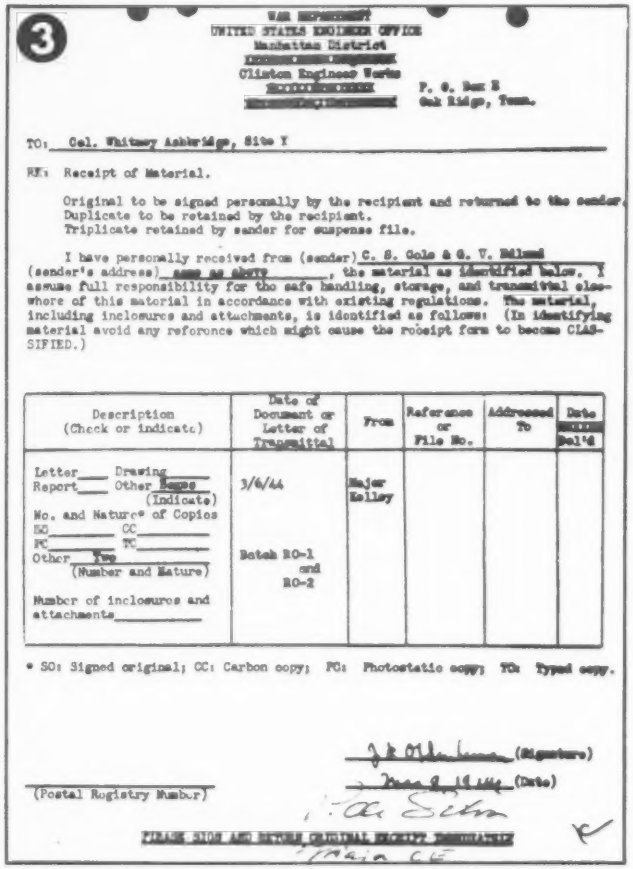
Clinton S. Cole (Signature)

(Date)

(Postal Registry Number)

PLEASE SIGN AND RETURN ORIGINAL RECEIPT IMMEDIATELY

2



WAR DEPARTMENT
UNITED STATES ENGINEER OFFICE
Manhattan District
Clinton Engineer Works
P. O. Box X
Oak Ridge, Tenn.

TO: Col. Whitney Ashbridge, Site Y

RE: Receipt of Material.

Original to be signed personally by the recipient and returned to the sender.
Duplicate to be retained by the recipient.
Triplicate retained by sender for suspense file.

I have personally received from (sender) C. S. Cole & G. V. Edlund (sender's address) same as above, the material as identified below. I assume full responsibility for the safe handling, storage, and transmittal elsewhere of this material in accordance with existing regulations. The material, including inclosures and attachments, is identified as follows: (In identifying material avoid any reference which might cause the receipt form to become CLASSIFIED.)

Description (Check or indicate)	Date of Document or Letter of Transmittal	From	Reference or File No.	Addressed To	Date Rec'd Del'd
Letter___ Drawing___ Report___ Other Boxes (Indicate) No. and Nature of Copies SO___ CC___ PC___ TC___ Other Two (Number and Nature) Number of inclosures and attachments___	3/6/44 Batch RO-1 and RO-2	Major Kelley			

* SO: Signed original; CC: Carbon copy; PC: Photostatic copy; TC: Typed copy.

J. R. Oppenheimer (Signature)

May 9, 1944 (Date)

P. de Silva

(Postal Registry Number)

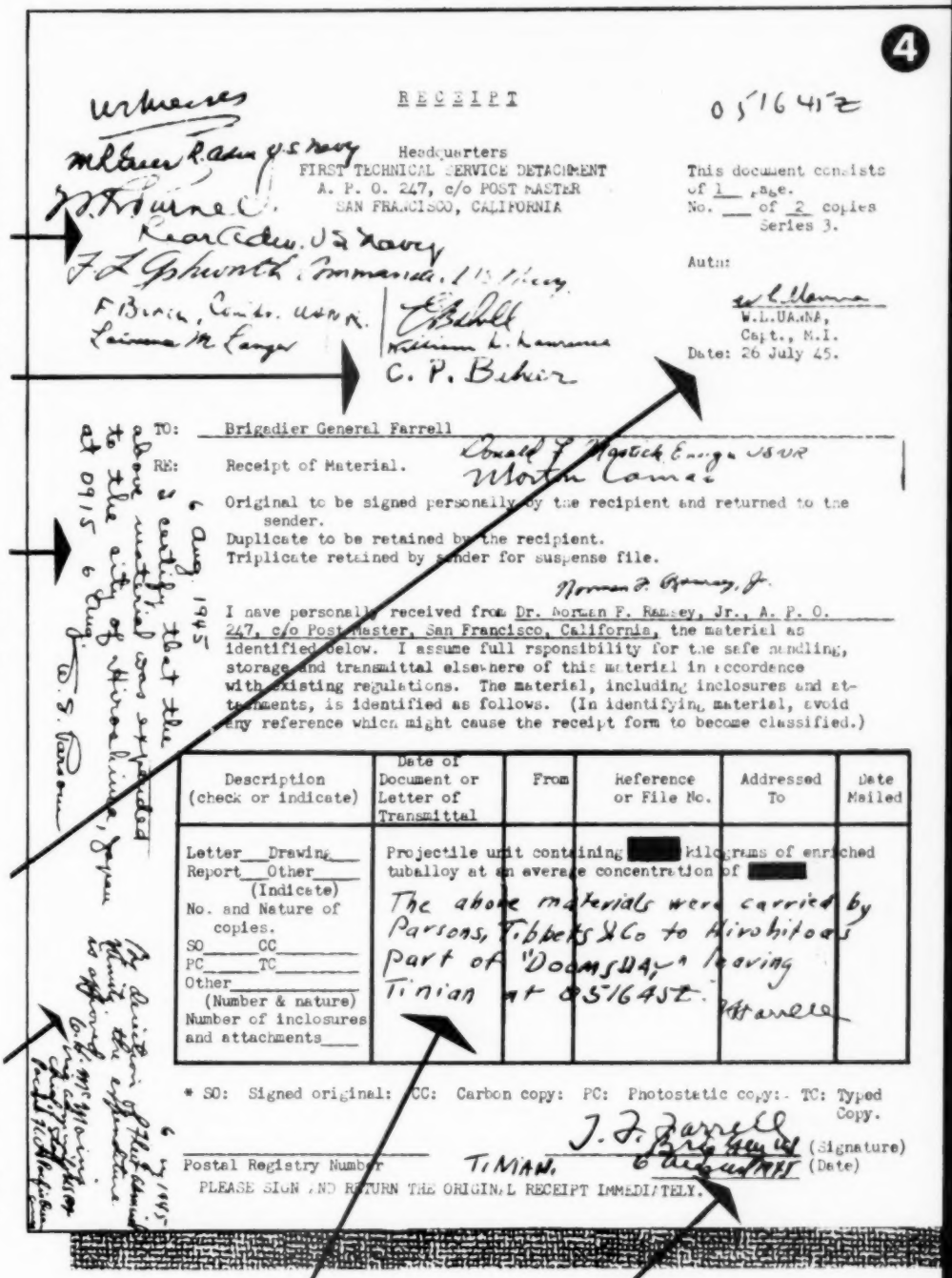
PLEASE SIGN AND RETURN ORIGINAL RECEIPT IMMEDIATELY

3

1 THREE DOCUMENTS on this page are receipts for first uranium-235 shipped from Oak Ridge to Los Alamos. Liquid diffusion plant (S-50) supplied feed for electromagnetic separation at Y-12. First Y-12 production was in Jan. and Feb. of 1944. Part of first "order-of-grams"-sized shipment was obtained by dissolving some stainless steel pipes and fittings of the plant, since U had deposited on them. Dr. Herbert A. Young of Tennessee-Eastman Corp., then operating Oak Ridge, transmitted the U from final processing (Dept. 195) to Lt. Lloyd R. Zumwalt, representing Maj. Wilbur E. Kelley, of Manhattan Engineers District.

2 COURIERS Clinton S. Cole and Gustav V. Edlund traveled by train to Los Alamos area. They carried special suitcases that looked ordinary outside but had gold plated-stainless steel boxes inside. Although great effort was made for anonymity, the mud-stained shoes of Oak Ridgers were always a tip-off to train porters.

3 DR. J. ROBERT OPPENHEIMER and Maj. Paul de Silva, Security Officer, signed for the U at Los Alamos. Col. Whitney Ashbridge, in charge for MED at "Site Y" was nominal recipient. This uranium was used in low-power water-boiler reactor built during spring, 1944. Reactor fuel was uranyl sulfate, 14.6% enriched, containing total of 565 grams of U-235.



4

Witnesses

RECEIPT

0516 45Z

Headquarters
FIRST TECHNICAL SERVICE DETACHMENT
A. P. O. 247, c/o POST MASTER
SAN FRANCISCO, CALIFORNIA

This document consists of 1 page.
No. ___ of 2 copies
Series B.

Auth:
W. L. Uanna
W.L.UANNA,
Capt., M.I.
Date: 26 July 45.

Witnesses who signed in control room while awaiting plane's return were: Rear Adm. M. R. Greer, Commander-Tinian Naval Air Force; Rear Adm. W. R. Purnell, Naval headquarters liaison; Com. F. Birch, Laurence M. Langer, E. B. Doll, C. P. Baker, M. Comar, bomb development and testing; William L. Laurence, Manhattan District historian; Ens. Donald F. Mastick, assistant operations officer; Com. F. L. Ashworth, executive officer, bomb delivery group.

TO: Brigadier General Farrell

RE: Receipt of Material.

Original to be signed personally by the recipient and returned to the sender.
Duplicate to be retained by the recipient.
Triplicate retained by sender for suspense file.

I have personally received from Dr. Norman F. Ramsey, Jr., A. P. O. 247, c/o Post Master, San Francisco, California, the material as identified below. I assume full responsibility for the safe handling, storage and transmittal elsewhere of this material in accordance with existing regulations. The material, including inclosures and attachments, is identified as follows. (In identifying material, avoid any reference which might cause the receipt form to become classified.)

Description (check or indicate)	Date of Document or Letter of Transmittal	From	Reference or File No.	Addressed To	Date Mailed
Letter___Drawing___ Report___Other___ (Indicate) No. and Nature of copies. SO___CC___ PC___TC___ Other___ (Number & nature) Number of inclosures and attachments___	Projectile unit containing [redacted] kilograms of enriched tuballoy at an average concentration of [redacted] The above materials were carried by Parsons, Tibbets & Co to Hirohito's part of "DOOMSDAY" leaving Tinian at 0516 45Z.				

* SO: Signed original: CC: Carbon copy: PC: Photostatic copy: TC: Typed Copy.

J. F. Farrell
Brig Gen USA (Signature)
TINIAN, 6 August 1945 (Date)

Postal Registry Number

PLEASE SIGN AND RETURN THE ORIGINAL RECEIPT IMMEDIATELY.

6 Aug. 1945

I certify that the above material was expended to the city of Hiroshima, Japan at 0915 6 Aug.

(s) W. S. Parsons

Auth.: (s) W. L. Uanna, Capt., M. I.
Date: 26 July 1945

6 Aug. 1945

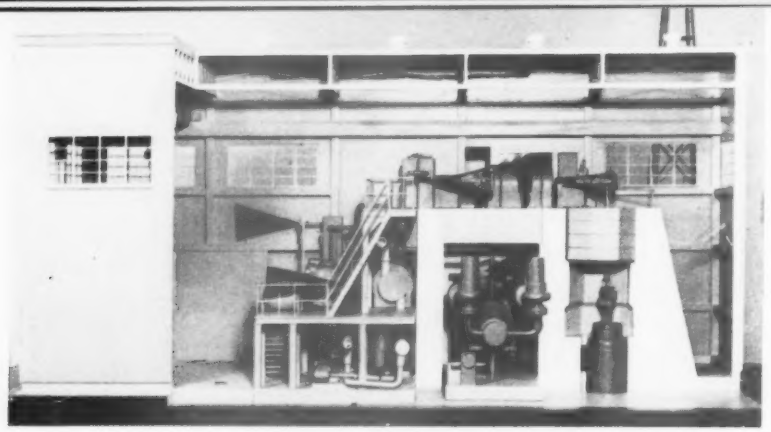
By direction of Fleet Admiral Nimitz, the expenditure is approved.

(s) G. H. McMorris
Vice Admiral, USN
Chief of Staff Pacific Fleet &
Pacific Ocean Areas

The above materials were carried by Parsons, Tibbets & Co. to Hirohito's part of "Doomsday" leaving Tinian at 0516 45Z

(s) T. F. Farrell

4 REALIZATION OF PURPOSE of Manhattan Project is depicted in this receipt for Hiroshima bomb. "Projectile unit containing x kilograms of enriched tuballoy at an average concentration of x" reached Tinian Island in four parts. A cruiser carried the projectile components and part of the U; remainder was flown in three airplanes. Brig. Gen. Thomas F. Farrell, in charge at Tinian, received the material for the Army. Deliverer was Dr. Norman F. Ramsey, Jr., chief scientist under Capt. W. S. Parsons (USN), leader of Los Alamos Bomb Delivery Group that actually engineered the bomb into being.



MODEL of APPR with reactor shown at far right. Shielding plugs are above reactor

How to Test a Nuclear Power Plant

A contract will be let about Jan. 1, 1955, for the Army Package Power Reactor (APPR), the first reactor to be built on a lump-sum basis. Strict specs have been set by AEC and Army. Because experience gained on this project will be useful on others, here are details of reactor test requirements and features of the contract to be negotiated

THIRTY-THREE COMPANIES or industrial groups (see NU, Aug. '53, p. 56 for names) are hard at work preparing bids on the 1,700 electrical-kw Army Package Power Reactor (APPR) to be built on a five-acre tract at Fort Belvoir, Va., about 18 miles south of Washington, D. C. Invitations were sent out by the Atomic Energy Commission and the Army in late August, and responses are due Nov. 19.

Although APPR-generated power will be used to serve needs of the site, a principal objective of AEC on this job is to obtain detailed cost information relating to design, construction and operation. This will be facilitated by the fact that only lump-sum proposals will be considered.

Design of the reactor, which is to produce 10 Mw of heat, is based on an Oak Ridge National Laboratory conceptual design of a pressurized-water package power reactor. The contractor will be responsible for detailed design and fabrication of all parts of the APPR—plus its performance. He will also be responsible for training an operating crew.

Presumably, the contractor will have to be a company knowledgeable and experienced in the reactor field, because AEC will require him "to perform a significant portion" of the work with his own force.

Test Requirements

Development and execution of test, inspection and operational procedures are contractor responsibilities. A 700-hr performance test of the power plant under designated operating conditions will be required to demonstrate that contract objectives have been met.

Functional integrity of the system, plant and facilities must be demonstrated as components are put in place and prior to loading the core with fissionable material.

As each piece of equipment is put in place, the inspection procedure shall demonstrate that the unit is on foundations or supports true and plumb, is securely fastened against the forces developed by the unit that could cause undue movement, slippage or vibration, and is installed to perform its designed function freely.

Each pressure vessel, as it is put in place and connected to associated piping or controls, shall be subjected to a test procedure to indicate the installed unit will perform its designed functions at operating pressures without exceeding the leakage allowance.

All valves and shut-off controls associated with the pressure vessels and their piping shall also be subjected to a test demonstration to indicate they are performing the control function without exceeding the leakage allowance.

Leakage allowance. General requirement for system leaktightness is to insure that radioactive materials escaping from the system shall not raise radioactivity levels in the environment above AEC tolerance levels.

In the primary loop, all equipment with seals or packing through which leakage normally occurs shall be blanked off and a helium leak test performed under vacuum on the remainder of the system. No leak shall be detectable by a Consolidated Engineering Co. detector, or equivalent, used at maximum sensitivity.

With the system at operating pressure and temperature, flanges and weld joints shall be inspected for leakage by observation and by a condensation method.

Leakage of fluid from all seals and packings in the primary loop shall be checked to insure that the amounts are not in excess of design quantities.

Leakage from conventional portions of the plant shall not exceed commercial practices for a new power plant.

Rotating machinery. Motors,

Safety Features and Requirements

The reactor design of the successful bidder is subject to approval by AEC's Advisory Committee on Reactor Safeguards. Actions of this committee may result in the need for design changes.

The reactor safeguards requirements, according to AEC, are:

"The general requirements for a structure at the proposed site are that it should prevent the emission to the environment of quantities of radioactive material which are biologically hazardous under any credible accident or operating condition which may occur. Any containment design must allow access to the reactor for loading, inspection, maintenance, and replacement of all mechanical components. Provisions shall be made for controlled release and filtering of any radioactive material prior to reactivating the building after a nuclear incident.

"One of several practices that has been used in other reactor plants is to place the reactor, including all portions of the primary coolant system and other associated equipment through which radioactive material may be discharged, in a gas-tight enclosure. The gas-tight enclosure is then capable of containing the maximum pressure resulting from a sudden release of the radioactive flash steam from the high pressure, high temperature water in the primary coolant system due to severe rupture of that system. The ventilation system for the gas-tight enclosure provides for the controlled release of gases through appropriate filters."

Contractor must show AEC's Advisory Committee on Reactor Safeguards that the structure for the proposed site will prevent emission of hazardous quantities of radioactive material to the surrounding area in the event of any credible accident.

pumps, and rotating machinery shall be tested when put in place and connected to the system. The procedure will indicate that equipment is turning in the proper direction without binding or galling of bearing seals, excessive vibration, overheating, or operation beyond design parameters.

Instrumentation. All instrumentation shall be tested and inspected to demonstrate that each component is properly mounted plumb, without vibration, and is connected to read or record on-scale values in the proper direction.

Noncritical Test Run

After completion of preliminary tests, contractor shall develop and execute a non-nuclear test of the entire plant cycle at design operating pressure and temperature.

Development and execution of this test shall be accomplished to: demonstrate integrity of entire system with regard to operating conditions, including allowed leaktightness of welds, joints, packing glands and inspection holes; show that the control rods satisfactorily perform all mechanical functions that might possibly be required of them during nuclear operations; establish that techniques and processes for controlling contaminants in the primary coolant system are functioning as designed; be certain that all reactor system equipment is operating properly while direct inspection is still possible; demonstrate practicability of maintenance procedures.

The core shall be mocked-up by loading it with nonuranium dummy fuel elements made of the same material as the structural material employed in the actual fuel elements. Contractor may select the length of time he desires to continue the noncritical test, but it shall last no less than seven days.

Contractor shall prepare and submit for AEC approval a preliminary draft of an APPR operating procedures manual. Development and execution of the noncritical test shall be geared to the operating manual and startup procedures therein. Control-rod action, corrosion tests, non-nuclear and nuclear instrumentation, and remote replacement or repair of equipment must be demonstrated.

Control-rod action. The following demonstrations shall be made and continued as long as is necessary to provide reasonable assurance to AEC of successful control-rod action throughout the expected lifetime of the first core.

Control rods shall be actuated to demonstrate that they move freely with no sticking or delay due to friction that would affect safe reactor operation. Control-rod drive and release mechanisms and indicators shall be actuated to demonstrate proper operation. Accuracy and preciseness of the control-rod position indication system shall be demonstrated. Response of the control system to simulated nuclear signals shall be measured and made to agree with design requirements.

Corrosion tests. Measurements of corrosion will be made under primary-coolant operating temperature, pressure, and flow conditions with dummy fuel elements in place. Electrical conductivity will be measured at least every six hours in the main circulating part of the primary loop. Chemical analysis and flow rates in the bleed-off system (if used) shall be measured frequently enough to assure reliable estimates of the amount of corrosion. Accumulations in the filter-ion exchanger (if used) shall be collected at the end of the run and measured.

Dummy fuel elements will be inspected for embrittlement, pitting and deposition after corrosion runs.

Based on corrosion tests, water-treatment procedures will be modified (if necessary) prior to power operation to assure safety from excessive coolant activation and fuel-element failure within designed nuclear life.

Non-nuclear instrumentation. Readings on all necessary flowmeters, thermometers, and other instruments shall be taken, so that operating conditions will be recorded and controlled. Information obtained must be adequate for calculating over-all heat balance at any time using practice generally accepted for steam plants.

Nuclear instrumentation. After installation, continuity and signal tests of all detecting components, recording circuits and control circuits will be made, using procedures developed for the particular systems. Signals simulating high flux levels and short periods will be applied to the trip circuits to insure design response.

Radiation detectors will be tested by means of standard radiation sources. All "failures" that relate to safety of the operating system will be induced and the response checked against design requirements.

Remote repair. It shall be demonstrated by actual performance that the

What A Bid Must Contain

Contractors' bids to be submitted Nov. 19 must include: flow diagram and heat balance of system; site layout showing utilities; description of buildings; statement of facilities to be used on job, with names of subcontractors and vendors; details on who will fabricate fuel elements and control rods; detailed shield design; description of safety features and block diagram of circuits and interlocks; statement of what research and development contractor will do; performance schedule; figures on guaranteed minimum and gross net electrical output of plant; and contract price—with or without six-month operating test.

Incentive Plan

During the six-months operating test, the contractor will receive bonuses for good operation of the plant: 1, if shutdown time during the course of a month does not exceed a total of 120 hr, the contractor will be paid an additional $\frac{1}{24}$ of the maximum price for the test; 2, if shutdown in any month does not exceed a total of 60 hr, the contractor will get an additional $\frac{1}{24}$ of the total price; 3, for each period of 400 hr of continuous operation up to and including a maximum of six such periods, the contractor will be paid an additional $\frac{1}{24}$ of the total price.

Fuel Elements, Control Rods

AEC prefers that contractor supply, or subcontract for, control rods and stainless-steel-clad enriched-uranium fuel elements (AEC to supply fuel). However, if contractor desires, AEC will act as subcontractor to have ORNL approve and fabricate one complete core plus 50% spare fuel elements and 100% spare control rods (including absorber and fuel sections) within about 6–8 months. For this work AEC will add $140,000 to the contractor's bid. Minimum required fuel-element life is six months—this requirement is less than previously had been anticipated.

---

following items of equipment can be replaced or repaired within the specified time (not including cooling-off period) in accordance with operating manual procedures: replace all fuel assemblies, 24 hr; replace all control rods and accompanying drive mechanisms, 24 hr; repair plugged tube in primary heat exchanger, 8 hr; replace rupture disks, 4 hr; replace seal popoff valve, 4 hr; replace high-pressure ion exchange equipment (if used), 4 hr.

In performing these operations, the entire shield, or a mockup, must be in place (except for blocks and plugs designed to be removable for the repairs in progress). No more than eight men can be used, and AEC radiation tolerance standards must not be exceeded.

Critical-Reactor Performance

After completion and approval of noncritical inspections and tests, the contractor shall develop and execute a test and inspection program of high- and low-power performance to demonstrate that the reactor can be made critical, brought to low-power and then to full-power operation as outlined in the operating manual with full assurance of the operation of all normal emergency signal, scram, and shutdown devices.

This test procedure shall: demonstrate (during the loading operation), by frequent and accurate measurements of the effective multiplication factor and of control rod value, that an adequate margin of safety is provided at all times; demonstrate, by using values obtained from control-rod calibration and temperature and pressure coefficients of reactivity, that a configuration has been obtained that is controllable throughout the core's life cycle; insure that every reasonable precaution is taken to prevent an accident that could result in injury to personnel or damage to the reactor plant or to the surrounding area.

In general, the contractor must conduct tests and calibrations at appropriate stages of this testing program to determine that all instruments are in working order and are giving indications that represent the state of the entire plant with sufficient accuracy for safety and confidence. Control mechanisms and circuits and safety devices and circuits also must be checked and tested to determine that their operation is reliable and in accordance with the design. In addition, the contractor must design and perform tests and measurements to demonstrate that the operating manual contains complete, concise instructions for all portions of the operating procedure.

Control-rod calibration. Each control rod will be calibrated over its entire length with various settings of other control rods. Sufficient combinations of rod settings must be used to determine all significant control-rod effects. Peripheral fuel elements may be added or removed to extend the range of these measurements.

Results of these calibrations, together with the contractor's calculations of core reactivity as a function of fuel and poison concentrations, will be used to demonstrate that the design specifications for control-rod worth will be met over the core's entire designed operating life.

Temperature coefficient. Primary-coolant temperature should be raised slowly and by means of a source other than reactor power. During this rise the temperature and pressure coefficients of reactivity will be measured at several points, including room temperature and operating temperature.

Rise to power. Measurements on reactor and system behavior will be made at low power levels ($\simeq 0.1\%$ of full). As experience and confidence are gained, the system will be raised slowly and carefully to full power.

High-power testing. The emergency cooling system should be tested in the following way: 1, with the reactor at power, bypass scram signal for failure of primary coolant pump or flow; 2, bring boiler to operating temperature and pressure; 3, bring reactor to power level equal to maximum fission-product-decay heating power expected 1 sec after shutdown; 4, shut off power to primary coolant pumps and pressurizer; 5, decrease reactor power at not more than the rate that fission-produced-decay power would decrease; 6, make adequate measurements of temperatures and pressures to demonstrate that primary coolant does not boil.

Also, the plants response to changes in generator load must be tested. Load changes should be used that vary from small, slow changes to large, sudden changes, including rapid changes from 10% to full load and a rapid change from full load to no load. During this

test, measurements of temperatures, pressures, and flows should be made. If the plant is equipped with automatic control (a servomechanism), these tests should be performed both with and without the servo, as far as safety will allow.

Plant Performance

After completing critical-reactor performance tests, and after approval is obtained from AEC, the contractor shall subject the plant to a 700-hr performance test and a six-month operating test.

700-hr performance test. This test is intended to demonstrate reliable operation of the over-all plant. The contractor shall operate the plant in a safe manner for a continuous period of 700 hr at an electric generation rate designated by AEC (not to exceed the designed rate). The contractor will be allowed outage or downtime consisting of 40 hr out of the 700 hr. Outage or downtime is defined as time during which the plant does not satisfy the designated load.

During performance of this test, when AEC requests, the contractor shall demonstrate that the radiation monitoring system is in proper operation, and shall make a radiation survey of the entire building while the reactor is operating at full power.

Full and complete data shall be logged or recorded continuously and automatically (instrumentation provided by contractor) to permit an analysis of the plant performance during test operation.

Within the contract term the contractor may start and attempt to execute the 700-hr performance test as many times as necessary until successful performance of the test is completed.

If, within the contract term or any extension thereof, the contractor fails to complete the 700-hr performance test successfully, the contractor shall be deemed to have failed to perform the work under this contract satisfactorily. In such event the contractor shall forfeit all or such portion of the holdback provided for (20% of the contract price) as AEC designates in its sole discretion. Upon successful completion of the test within the contract period or any extension thereof and upon acceptance of the APPR by AEC, the contractor shall be paid as provided in the contract.

Upon successful completion of the 700-hr performance test or expiration of the contract, whichever first occurs, the contractor shall place the APPR in a condition acceptable to AEC.

Six-month operating test. Upon completion of the 700-hr performance test, the contractor shall make any modifications and/or repairs indicated as necessary or desirable in the test and shall notify AEC of his readiness to proceed with the six-month operating test. Such notice will in no event be more than 30 days following successful completion of the 700-hr test.

Upon notice to proceed, the contractor will bring the plant to power and continue to operate the plant for six consecutive months under AEC-designated load-demand conditions. During the six-month period the contractor will continue to bear full responsibility for the plant's efficient operation, service, and repair.

During the six-month operating test, payments shall be made to the contractor as provided in the contract. Such payments shall constitute the entire compensation of the contractor for the performance of this test. AEC reserves the right to make final acceptance of the plant at any time during this period.

Delays due to defects. If during the performance of either the 700-hr performance test or the six-month operating test, fabrication defects in the fuel elements or control rods cause the reactor to shut down and operation cannot be resumed by substitution of spares, and it shall be necessary to have further fabrication work performed on such elements or rods, the contract period shall be extended by the time required for the performance of such fabrication work. Shutdowns due to failure of fuel elements or control rods by reason of fabrication defects or otherwise, but where operation of the reactor can be resumed by substitution of available spare elements or rods, shall be the responsibility of the contractor and shall not constitute a basis for extension of the contract period. Shutdowns due to failure of fuel elements or control rods for any reason except fabrication defects shall be the responsibility of the contractor, even though further fabrication is required, and shall not constitute a basis for extension of the contract period. END

Contract Items

Contractor will have 36 months to have plant ready for six-month operating test. AEC might require 100% (of contract price) performance bond and a payment of bond (for labor and materials) up to 50% of contract price. Contractor will receive bonuses for good plant performance during the six-month operating test.

If the AEC Advisory Committee on Reactor Safeguards declares the containment measures proposed by the contractor to be inconsistent with the maximum credible accident or operation condition for which the measures are to provide, AEC must decide whether it agrees with its committee or whether it feels the disagreement is due to opinion differences. The contract will be modified accordingly.

The Government will be responsible for damage from radioactive, toxic, explosive, or other hazardous properties of source, fissionable or radioactive materials used.

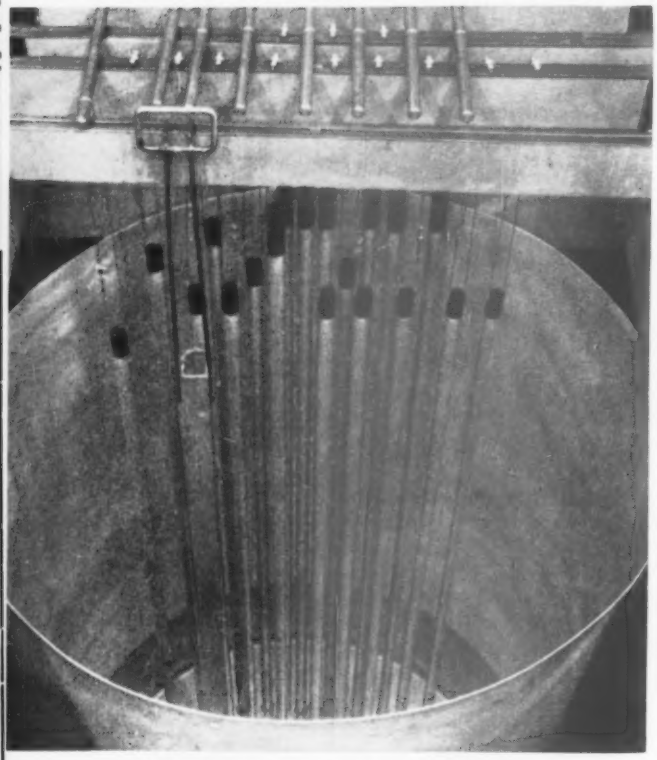
No patents will be permitted on the reactor or its components—but they will be permitted on other phases (i.e., the steam and generating systems).

Work Schedule

Phase I. Completion of progress schedule, flow diagram, heat balance.
Phase II. Preliminary designs of system components, details of plant, site, and safety plans.
Phase III. Specifications and drawings for fabrication and construction.
Phase IV. Fabrication and construction.
Phase V. Testing.

Operating Personnel

Building design will be based on at least a 32-man crew. There will be a 7-man operating crew consisting of: superintendent, operator, technician, mechanic, helper, janitor and guard. There will be a director of training and two complete training crews each consisting of the seven classifications listed above. Provision must be made for ten visiting engineering or technical trainees. The contractor will be responsible for training the Government operating crew.



Criticality of Normal-Water Natural-Uranium Lattices

FIG. 1. Arrangement of tank and rods

By ROLF PERSSON
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A DIVERGENT chain-reacting system cannot be achieved with a homogeneous mixture of natural uranium and ordinary water. But with a heterogeneous system it might be possible. Using theory (*1*) and allowing for the increased fast-fission effect in compact lattices, a maximum theoretical value for k of about 0.97 is calculated for a distance between rods of 4.7 cm when the rod diameter is 3.0 cm, which was the only rod diameter available. On account of the small distance between rods, the theoretical calculations using simple diffusion theory might be considerably in error.

Experimentally, the multiplication constant of a medium can be found in at least two ways. In ordinary exponential experiments the *differential properties* (the buckling, or the "Laplacian") of the neutron distribution far away from the source is determined. It is also possible, on the other hand, to *integrate* the neutron density over the whole volume (core and reflector) including the source, and from this obtain the departure of the multiplication constant from unity (*2*). Both methods were used in these measurements.

Equipment

Figures 1 and 2 show how 129 uranium rods, each 3.0 cm in diameter and about 2 m long, were suspended in a hexagonal lattice in a tank containing distilled water. The uranium rods were canned in 0.03-cm-thick aluminum tubes. The distance between the centers of the rods was varied from 4.0 cm to 6.5 cm in steps of 0.5 cm.

The tank was 1.2 m in diameter and 2 m high. Since the diameter of the uranium core was always less than 0.8 m, the water reflector could be considered infinitely thick.

The neutron source in most cases was 0.6 c of RaBe, and the detectors were boron trifluoride chambers of various shapes. Buckling was measured by a small glass chamber 1.0 cm in diameter and 3 cm in effective length; it was filled to 1 atmosphere of BF_3 enriched in B^{10}. The detector was joined to the preamplifier by a coaxial cable and protected by an aluminum tube.

In the integrating experiment we used a brass chamber, 2.5 m long and 1.5 cm in diameter, that integrated the neutron intensity in the axial direction. The detectors were centered with respect to three neighboring rods by a triangle mounted at the end of the probe. The preamplifiers were supported by a bridge, which could be moved in the vertical direction. In this way the vertical position of the detectors could be varied.

Material Buckling

In ordinary exponential experiments the neutron distribution is measured at some distance away from the source and the boundaries. From these measurements the material buckling, $B_m^2 = \Delta n/n$, is determined; the infinite multiplication constant, k, is obtained (to a good approximation) from the formula

$$B_m^2 = (k - 1)/M^2 \qquad (1)$$

where M^2 is the migration area for

Multiplication constant of a hexagonal lattice of 3.0-cm uranium rods in ordinary water was determined as a function of rod spacing. A differential method and an integrating method were used. Maximum value of k_∞ was 0.970 ± 0.015 when rods were spaced 4.5 cm

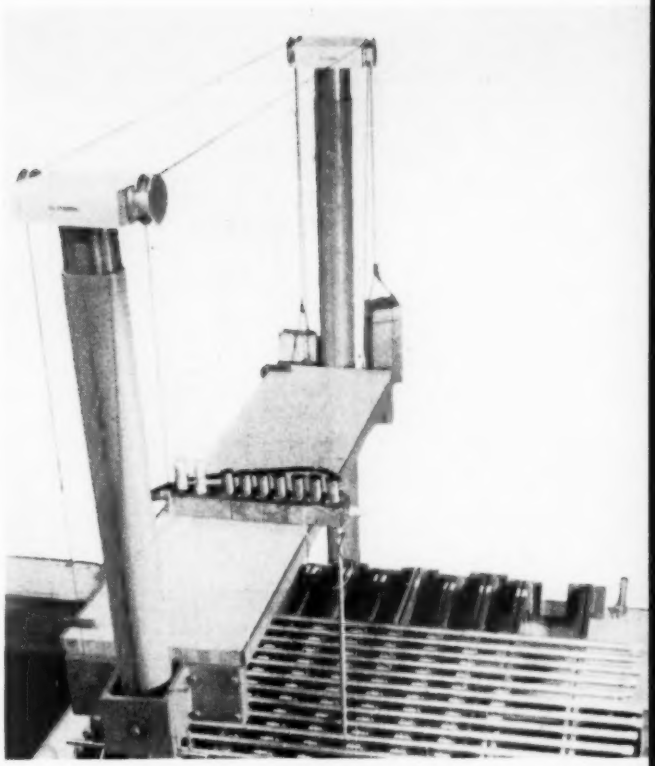

FIG. 2. Bridge-mounted preamplifier was movable in vertical direction

fission neutrons. In a cylindrical arrangement the buckling is a sum of a radial part, α^2, and an axial part, $-\gamma^2$.

If there were no reflector, the *radial* distribution at a sufficient distance from the source would be given by the Bessel function $J_o(\alpha r)$, where $\alpha = 2.405/R$ and R is the extrapolated radius. The radial part of the buckling can then be accurately determined from a measurement of the extrapolated radius. In a diagram showing $1/\alpha$ as a function of the lattice distance, the measured points would obviously lie above a line $1/\alpha = R_c/2.405$, where R_c is the geometrical radius of the core.

In our measurements the radial part of the buckling cannot be calculated from the extrapolated radius because of the presence of the water reflector (see Fig. 3). Instead, we have calculated it from measurements near the center of the core, where the influence of the reflector is negligible. If the neutron density in this region can be expanded in a power series

$$n(r) = A - Br^2 + Cr^4 - \ldots \quad (2)$$

it is easy to show that the radial part of the buckling at the center is

$$\alpha^2 = 4B/A \quad (3)$$

where A and B were determined by fitting the data to Eq. 2, using the method of least squares.

For the lattice distances 4.0 and 4.5 cm, irregular fluctuations in the measured distribution prevented determination of the radial buckling. These fluctuations are probably due to irregularities in the lattice, since the uranium rods were not always straight and the method of suspension did not allow very high precision. These factors would become important for small lattice distances.

For intensity reasons the radial distribution was measured at a vertical level where the higher radial harmonics had not decayed completely. Because of the contribution of these harmonics, measured values of $1/\alpha$ were lower than they would be if only the fundamental mode were present. Experimental values of $1/\alpha$ are shown in Fig. 4. The core radius, R_c, and lattice spacing, a, are related as $129\sqrt{3}\,a^2/2 = \pi R_c^2$.

Far away from the source, where the radial harmonics have disappeared, the *axial* distribution decays exponentially with a relaxation length L_r. The results are shown in Fig. 5. At the level where the radial distribution was measured, the presence of radial harmonics resulted in deviations from a purely exponential behavior. The axial buckling, $-\gamma^2$, in this plane is somewhat larger in magnitude than the value $1/L_r^2$, which is valid for the exponential distribution. L_r and γ^2 are given in Table 1.

Because the extra absorption in the detector changes the multiplication constant, the measured distribution will not be exactly proportional to the undisturbed one. However, calculations show that this influence was negligible in these experiments.

Experimental results are collected in Table 1. Values of M^2 used to evaluate k from Eq. 1 have been calculated by means of diffusion theory and are probably correct to within 5%.

Integrating Method

In this case the neutron source was placed in the middle of the tank, and the neutron density was integrated over the core and reflector. Production

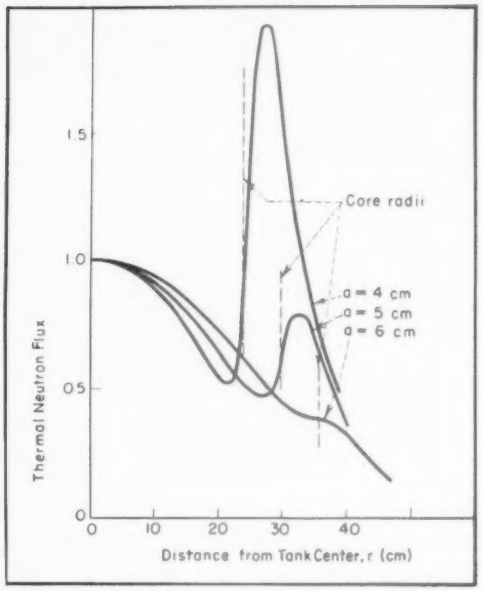

FIG. 3. Neutron distribution for different lattice spacings

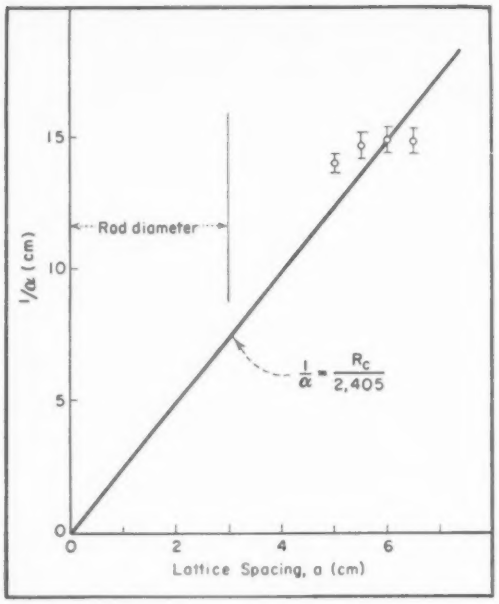

FIG. 4. Experimental values of $1/\alpha$ as function of lattice spacing

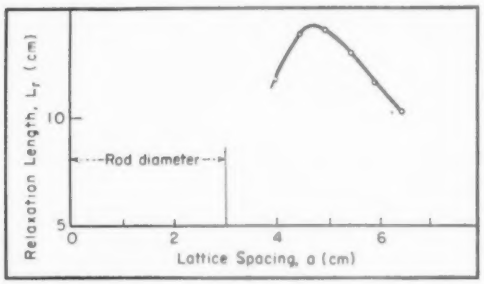

FIG. 5. Relaxation length as function of lattice spacing

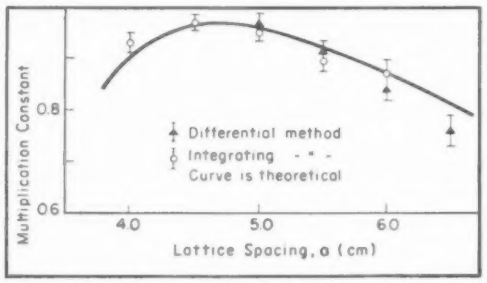

FIG. 6. Multiplication constant as function of lattice spacing

rate of neutrons must equal absorption rate, and thus

$$QY + \frac{k}{p}\left[\int_c qdV + \delta Q\right] = \frac{1}{p}\int_c qdV + \int_r qdV \quad (4)$$

where Q = source strength (n/sec), Y = multiplication factor of the source neutrons due to fast fission, q = rate of neutrons slowed down to thermal energy per unit volume (n/cm³/sec), δQ = net leakage of slow neutrons from reflector to core (n/sec), and p = resonance escape probability. Indices c and r refer to the core and to the reflector respectively. Introducing $\int_c qdV = Q_c$, Eq. 4 can be transformed to

$$k - 1 = \frac{(Q_r - \delta Q) - QY}{Q_c + \delta Q}\, p - \frac{\delta Q}{Q_c + \delta Q}(1 - p) \quad (5)$$

If we now integrate the diffusion equation of the slow neutrons in the *reflector* over the volume, we obtain

$$\int_r D_r \nabla^2 \phi \, dV - \int_r \Sigma_r \phi \, dV + \int_r qdV = 0 \quad (6)$$

From Eq. 6 the following relations are obtained

$$\delta Q = -\int_r D_r \nabla^2 \phi \, dV = D_r 2\pi R_c v \left(\frac{\partial n}{\partial r}\right)_{r=R_c} \quad (7)$$

where R_c is the radius of the core, and

$$Q_r - \delta Q = \Sigma_r v \int_r n \, dV = \Sigma_r v N_r \quad (8)$$

The integral N_r is obviously the quantity evaluated from the measurements.

For the *core* we get in the same way

$$Q_c + \delta Q = \Sigma_{c_{avg}} v N_c \quad (9)$$

where $\Sigma_{c_{avg}}$ is a mean value of the macroscopic cross section over a cell weighted according to the cell's flux distribution, which can be calculated

by diffusion theory. In the experiment, the neutron density in the core was measured at the midpoint between three neighboring rods. The integral N_c was obtained by integration of a smooth distribution through these points, and the result was then multiplied by the ratio between the average and the maximum flux in the cell.

With the uranium rods removed and integrating over the total volume

$$Q = \int \Sigma_o \phi \, dV = \Sigma_o v N_o \qquad (10)$$

using index "o" for this *calibration* measurement.

If we remember that $\Sigma_r = \Sigma_o$, Eq. 5 can now be transformed to

$$k - 1 = \frac{\Sigma_o (N_r - N_o Y)}{\Sigma_{c_{avg}} N_c} p - \frac{D_r 2\pi R_c}{\Sigma_{c_{avg}} N_c} \left(\frac{\partial n}{\partial r}\right)_{r=R_c} (1 - p) \qquad (11)$$

In reference (*2*) the leakage of slow neutrons is neglected.* But in our measurements this effect is not negligible for the most compact lattices.

The fast-fission multiplication Y of the source neutrons was calculated using certain simplifying assumptions. The average fission cross section for the primary Ra-Be neutrons was estimated as 0.63 barn, and the elastic and inelastic cross sections were taken to be the same as for fission neutrons, namely 1.5 and 2.47 barns respectively. The value of the resonance escape probability p was calculated according to formulas given in reference (*1*).

The choice of the inaccurately defined boundary between core and reflector is a source of uncertainty in the integrating method when it is applied to a heterogeneous system. We have taken this boundary to be a circle enclosing an area corresponding to the cell area times the number of rods. The gradient $\partial n/\partial r$ was obtained from the measured distribution in the reflector.

Results are given in Table 2. The uncertainty in k is based on assumed errors of 10% in N_c, $\Sigma_{c_{avg}}$, $(Y - 1)$ and p. The error in N_r (also about 10%) corresponds to an uncertainty of 1 cm in the position of the boundary. The gradient, $(\partial n/\partial r)$, is estimated to be correct within 20%.

The final results for the multiplication constant can be expected to be too small by about 0.5% or less, due to leakage from the top and the bottom of the arrangement. However, this is within the errors of the measurements.

TABLE 1—Multiplication Constant from Measurements of Buckling; $B^2_m = \alpha^2 - \gamma^2$

a (cm)	L_r (cm)	γ^2 (10^{-3} cm^{-2})	α^2 (10^{-3} cm^{-2})	B^2_m (10^{-3} cm^{-2})	M^2 (cm^2)	k
4.0	11.70 ± 0.15					
4.5	13.88 ± 0.11					
5.0	13.93 ± 0.10	5.70 ± 0.15	5.1 ± 0.4	−0.6 ± 0.4	50	0.970 ± 0.020
5.5	12.89 ± 0.12	6.50 ± 0.20	4.7 ± 0.4	−1.8 ± 0.5	47	0.915 ± 0.020
6.0	11.55 ± 0.11	8.0 ± 0.3	4.5 ± 0.3	−3.5 ± 0.5	45	0.840 − 0.020
6.5	10.28 ± 0.13	9.9 ± 0.4	4.5 ± 0.3	−5.4 ± 0.5	44	0.76 ± 0.03

TABLE 2—Multiplication Constant by the Integrating Method; $N_0 = 53.9$, $\Sigma_0 = 0.0215$ cm^{-1}, and $D_r = 0.16$ cm

a (cm)	N_r	N_c	$\Sigma_{c_{avg}}$ (cm^{-1})	Y	p	$\left(\frac{\partial n}{\partial r}\right)_{r=R_c}$	k
4.0	55.1	34	0.160	1.189	0.69	$+6.50 \times 10^{-2}$	0.930 ± 0.020
4.5	57.3	63	0.121	1.152	0.79	$+3.8 \times 10^{-2}$	0.970 ± 0.015
5.0	40.9	80	0.095	1.122	0.84	$+0.6 \times 10^{-2}$	0.950 ± 0.015
5.5	23.0	85	0.078	1.102	0.88	0	0.895 ± 0.020
6.0	17.5	94	0.066	1.084	0.90	-0.15×10^{-2}	0.87 ± 0.03

Discussion

Experimental values for the multiplication constant obtained by the differential and integral methods are compared in Fig. 6 as functions of the lattice spacing. They are in good agreement. Also shown in this figure is a theoretical curve, calculated by diffusion theory (*1*). The calculation accounted for fissions produced in one rod by fast neutrons originating in the adjoining rods as well as in the same rod. For the small lattice spacings of the present investigation, this results in a substantial increase in the effect of fast fission (ϵ was calculated to be 1.08 for a spacing of 4 cm).

The differential method is more straightforward than the integral method for measuring the multiplying properties of a chain-reacting system. In the integrating method one has to apply several corrections to the measured quantities, and it is very difficult to estimate the errors in these corrections, which are found theoretically. When we only want to find whether k is smaller or larger than unity, we have to compare just two measured quantities in the differential method ($\alpha^2 > \gamma^2$ means that $k > 1$, and $\alpha^2 < \gamma^2$ that $k < 1$). But with the integral method we have to calculate the factor Y and the resonance escape probability p before any comparison can be made.

The rod diameter in this experiment was fixed by practical reasons and is probably not the optimum. Thus it is still an open question whether a self-sustaining chain reaction could be made to work in a natural-uranium ordinary-water system. While it is possible to increase the accuracy of small-scale measurements somewhat over that of the present results, it seems doubtful whether the question could be settled definitely except by a full-scale critical experiment. This would, however, require very large amounts of uranium (around 300 tons, if k were 1.01).

* * *

The author is indebted to the director of the physical department, S. Eklund, for allowing this work to be published, to G. von Dardel for valuable advice and stimulating discussions and to K. Wirtz for suggesting the integrating method. I also wish to express my gratitude to E. Blomsjö for the mechanical construction and to P. Holmén for technical assistance.

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* Correction also was forgotten in letter to *Nature* **174**, 265 (1954).

Isotope Production:

How to Choose Irradiation Time

Rate equations are well known in chemical kinetics. Radioisotope production involves similar mathematics. Rigorous analysis of the general rate equations governing isotope production and decay is presented, with usage shown for the cases of Au^{198}, Au^{199} and Tm^{170}

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IT IS THE PLAN of this article to consider reaction kinetics as applied to isotope production. The case of first-order products will be treated extensively. Application to two specific problems will then be presented.

General Rate Equations

A series of reactions starting with a substance that is transformed into a second substance that in turn is transformed into a third, and so on, is described by a sequence of differential equations. It is assumed that the rate of each transformation is proportional to the amount of the substance undergoing transformation and to a characteristic reaction constant. Thus

$$\begin{aligned}\frac{dx_0}{dt} + k_0 x_0 &= 0\\ \frac{dx_1}{dt} + k_1 x_1 &= k_0 x_0\\ \frac{dx_n}{dt} + k_n x_n &= k_{n-1} x_{n-1}\end{aligned} \qquad (1)$$

These equations have the general solution

$$x_m = \sum_0^m {}_m a_j e^{-k_j t} \qquad (2)$$

If as a boundary condition we require that at time $t = 0$, $x_0 = 1$ and $x_j = 0$ for $j \neq 0$, the constants take on the values

$${}_m a_j = \frac{k_0 k_1 \cdots k_{m-1}(-)^m}{(k_j - k_0)(k_j - k_1) \cdots (k_j - k_m)} \qquad (3)$$

where the product in the denominator includes all differences except $(k_j - k_j)$.

This follows readily from Eq. 1 by induction for all constants except those of form ${}_m a_m$. Since x_m vanishes for $t = 0$, we have the additional requirement that

$$\sum_0^m {}_m a_j = 0 \qquad (4)$$

for all values of m greater than zero.

The fact that ${}_m a_m$ has the same form as ${}_m a_j$ is not obvious. However, we note that the general form can be expressed

$${}_m a_j = R_m(k_j) \qquad (5)$$

where $R_m(k_j)$ is the residue of the function

$$F_m(z) = \frac{1}{(z - k_0)(z - k_1) \cdots (z - k_m)}$$

at the point $z = k_j$. Since this function is analytic, the sum of the residues vanishes and, since the residue at infinity vanishes also, the sum of the residues for finite values of z must vanish independently. This sum is simply the sum of the coefficients ${}_m a_j$ over all values of j.

It is instructive and useful to obtain a power-series expansion of Eq. 2. This is

$$x_n = \frac{k_0 k_1 \cdots k_{n-1}}{n!} t^n \left[1 - \frac{t}{n+1}(k_0 + \cdots + k_n) + \cdots\right] \qquad (6)$$

This shows clearly that the function and its first $n - 1$ derivatives vanish when $t = 0$. It clearly defines the range where a single term in the expansion is of adequate accuracy. Also, it makes clear what is meant by the "order" of the product. The "order" is the same as lowest power of t appearing in Eq. 6.

It should be noted in passing that Eq. 4 has interesting applications in combinatorial analysis.

Physical meanings. The several constants k_j have the dimensions of inverse time. Each is characteristic of a certain type of destructive process. In many cases, more than one process is effective in destroying a substance. For example: Au^{198} can be destroyed by spontaneous decay to Hg^{198} and also by neutron capture to form Au^{199}. The decay constant must represent the sum of all destructive processes.

Each decay constant is also a formation constant for the next product down the line. Chain branching is readily handled by taking care to use a composite constant for the decay of a substance and using the components for

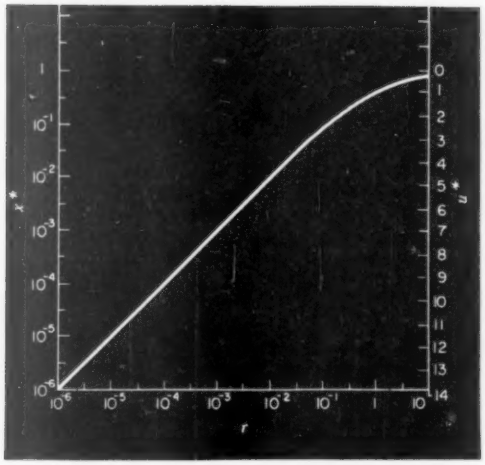

FIG. 1. Maximum isotope concentration and function u^* vs ratio of formation to destruction rate constants

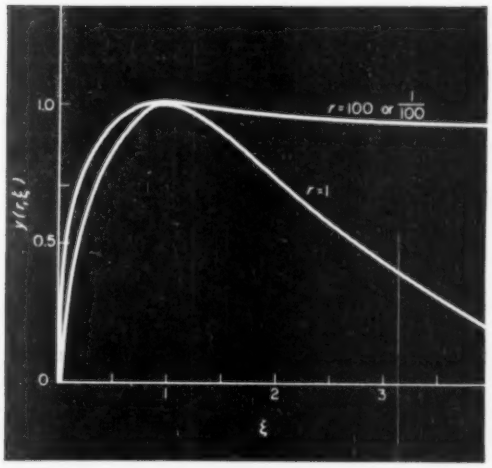

FIG. 2. Fraction of maximum yield vs fraction of time required to reach maximum, for various values of the ratio of formation rate to destruction rate

formation constants of the various branches of the chain.

First-Order Products

Most radioisotopes produced by in-pile irradiations are first-order products. The equation describing this reaction is

$$x_1 = \frac{k_0}{k_1 - k_0}\left(e^{-k_0 t} - e^{-k_1 t}\right) \qquad (7)$$

It will be more convenient to treat this equation if we transform the independent variable to $u = k_1 t$ and set $k_0/k_1 = r$. Then Eq. 7 becomes

$$x_1 = \frac{re^{-u}}{1-r}\left[e^{(1-r)u} - 1\right] \quad r \neq 1$$
$$= ue^{-u} \quad r = 1 \qquad (8)$$

We see that x_1 is a maximum when

$$u = u^* = \frac{-\ln r}{1-r} \quad r \neq 1$$
$$u^* = 1 \quad r = 1 \qquad (9)$$

For all values of u^* the corresponding value of x_1 is x^*, where

$$x^* = e^{-u^*} = (r)^{1/(1-r)} \qquad (10)$$

Significance. Thus there is a definite value of u that maximizes x_1. This value u^*, and the corresponding value x^*, are functions of r only. Figure 1 plots u^* and x^* vs r. The function x_1 thus has a typical form: it starts at the origin with an initial slope r, reaches a maximum at $u = u^*$, undergoes an inflection at $u = 2u^*$ and vanishes when u becomes infinite. Figure 6 illustrates this behavior.

Gold Irradiation

Isotope	*Cross section (barns)*	*Capture product half-life (days)*
Au^{197}	95	2.7
Au^{198}	38,000	3.15

Calculated Values

	X – 10	*MTR*
ϕ	5×10^{-3}	1
k_0	4.10×10^{-6}	8.20×10^{-4}
k_{11}	2.57×10^{-1}	2.57×10^{-1}
k_{12}	1.63×10^{-3}	3.26×10^{-1}
k_1	2.59×10^{-1}	5.83×10^{-1}
k_2	2.20×10^{-1}	2.20×10^{-1}
r	1.58×10^{-5}	1.41×10^{-3}
u^*	10.05	6.46
x^*	1.58×10^{-5}	1.56×10^{-3}
t^*	38.8 d	11.1 d

Yield Fraction vs Time

Expressions have been derived for the maximum yield, x^*, and the time, t^*, required to reach the maximum. (Equation 9 is actually for u^* which is proportional to t^*.) From a practical point of view one is usually satisfied with a less-than-maximum yield which can be reached in considerably less time. In order to establish a relation helpful in this problem, new variables are useful

$$y(\xi,r) = \frac{x(u,r)}{x(u^*,r)}$$
$$\xi = \frac{u}{u^*} = \frac{t}{t^*}$$

These variables are dimensionless, and represent respectively the ratio of yield at a given time to the maximum yield, and the ratio of time to the time required for attaining the maximum yield. A plot of y against ξ gives the desired relation.

$$y(\xi,r) = \frac{r^\xi - 1}{r-1}\, r^{(1-\xi)r/(r-1)} \qquad (11)$$

Direct substitution in Eq. 11 shows an unsuspected symmetry relation $y(\xi,r^{-1}) \equiv y(\xi,r)$. With somewhat more difficulty it can be shown that for values of $r \geq 1$, $y(\xi,r+\epsilon) \geq (\xi,r)$.

These relations have important practical applications. For a given value of the parameter r, the fraction of t^* required to reach a desired fraction of the maximum yield is given directly. Moreover, it has been established that this fraction is always less than it would be for r equal to unity. This follows from the fact that all curves in the r-family lie above the curve for $r = 1$, *viz*

$$y(\xi,1) = \xi e^{1-\xi} \qquad (12)$$

For example: a 90% yield is obtained for $r = 0.01$ when $t = 0.55t^*$; whereas if $r = 1$, the same yield requires $t = 0.75t^*$.

It is well to emphasize that the significant parameter is r. Rules of

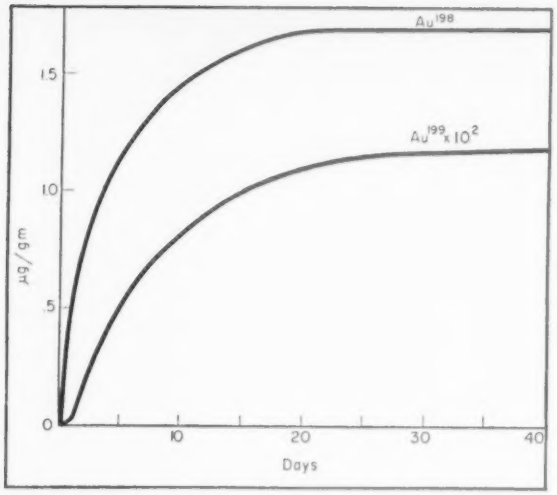

FIG. 3. Formation of Au^{198} and Au^{199} in flux of 5×10^{11} n/cm²/sec

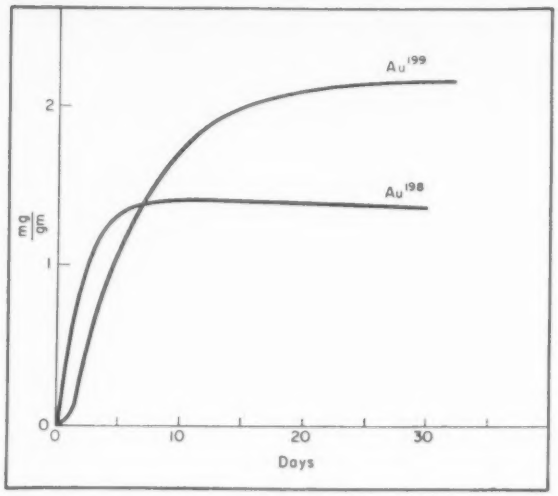

FIG. 4. Formation of Au^{198} and Au^{199} in flux of 10^{11} n/cm²/sec

thumb based on other parameters such as the product half life, although helpful at times, can not be expected to give satisfactory answers in all cases.

Production Applications

The preceding development has established the laws governing the formation of a first-order reaction product. The time at which a maximum is reached and the maximum value are determined by the two rate constants: k_0, the rate of formation from target material, and k_1 the rate of destruction.

The rate constants for reactions in a nuclear reactor are obtained from known physical constants; σ_t, the activation cross section of target, ϕ, the neutron flux, and $t_{1/2}$, the half-life of product, usually for spontaneous decay.

In terms of these quantities

$$k_0 = \sigma_t \phi$$

$$k_1 = \frac{\ln 2}{t_{1/2}}$$

It should be noted that if, instead of the half-life, the time to reduce the product to $1/n$ were given, we would have for k_1 the expression

$$k_1 = \frac{\ln n}{t_{1/n}}$$

If there is an appreciable cross section of the product material, σ_p, the two destructive processes must be added, and

$$k_1 = \frac{\ln 2}{t_{1/2}} + \sigma_p \phi$$

Thus the parameter r becomes

$$r = \frac{k_0}{k_1} = \frac{\sigma_t \phi t_{1/2}}{\sigma_p \phi t_{1/2} + \ln 2}$$

For small values of $\phi t_{1/2}$

$$r \approx \frac{\sigma_t \phi t_{1/2}}{\ln 2}$$

For large values of $\phi t_{1/2}$

$$r \approx \frac{\sigma_t}{\sigma_p}$$

It is at once evident that the time dependence of product material in a high flux is quite different from that in a low flux. It is also evident that indefinitely increasing the flux will not increase the product beyond the value determined by $r = \sigma_t/\sigma_p$.

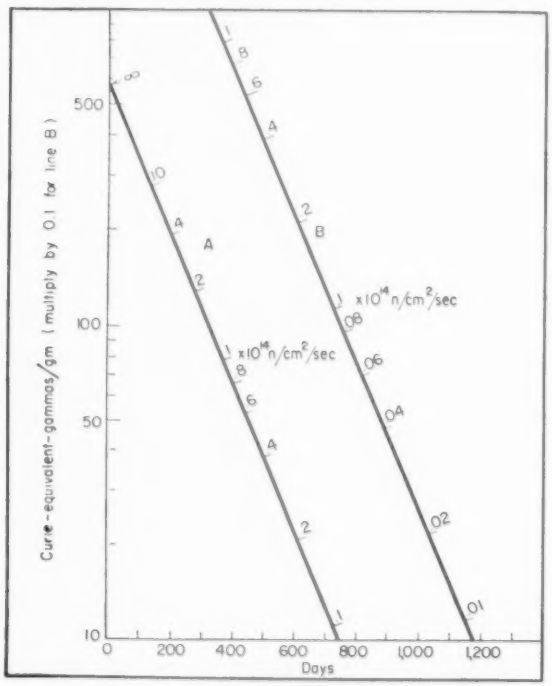

FIG. 5. Maximum Tm^{170} activity in curie-equivalent-gammas/gram vs irradiation time to produce maximum, with flux values spotted

It should be noted that if the product has a low cross section, the limiting value of r can become quite large. However, it is not permissible to assume a negligible product cross section merely because there is no information on the matter. It is not likely that the value of r will greatly exceed unity. If such should appear to be the case, it would be well to investigate the product cross section.

Two examples will be chosen to illustrate important points. The first will be the irradiation of Au^{197} to form the first-order product Au^{198} and the second-order product Au^{199}. This example shows well the dependence of product formation on flux, particularly for the second-order product.

The second example is the formation of Tm^{170} from Tm^{169}. This subject is of timely interest in view of the proposed use of Tm^{170} for portable radiographic units. Since high specific activities are required, this also serves to illustrate the desirability of high neutron flux.

Irradiation of gold. The physical constants are given in the table (p. 31). From them the following are calculated, for a flux of $\phi \times 10^{14}$ n/cm²/sec. Formation Au^{198}

$$k_0 = 8.20 \times 10^{-4}\phi/\text{day}$$

Destruction Au^{198}

$$k_{11} = 0.257/\text{day}$$
(decay to Hg^{198})
$$k_{12} = 0.326\phi/\text{day}$$
(neutron capture)
$$k_1 = (0.257 + 0.326\phi)/\text{day}$$

Decay Au^{199}

$$k_2 = 0.220/\text{day}$$

Two cases will be considered; $\phi = 5 \times 10^{-3}$ as typical of the X-10 reactor and $\phi = 1$ as typical of the MTR. The table shows a summary of the calculated values. From them, these equations are derived:

X-10 Reactor

$$x_1 \approx 1.58\,(1 - e^{-0.259t}) \times 10^{-5}$$
$$x_2 \approx (1.17 + 6.61e^{-0.259t} - 7.78e^{-0.220t}) \times 10^{-7}$$

MTR Reactor

$$x_1 = 1.405\,(e^{-8.20t\times10^{-4}} - e^{-0.583t}) \times 10^{-3}$$
$$x_2 \approx (2.16 + 1.31\,e^{-0.583t} - 3.47\,e^{-0.220t}) \times 10^{-3}$$

The curves for these equations are shown as Figs. 3 and 4.

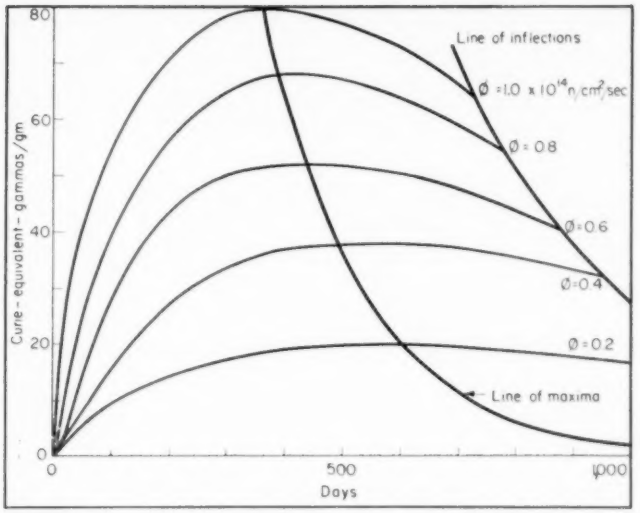

FIG. 6. Specific Tm^{170} activity vs irradiation time with flux as parameter

Irradiation of thulium. The constants involved are given below

Tm^{169} $\sigma_c = 120$ barns
Tm^{170} $t_{1/2} = 129$ days
$k_0 = 1.035 \times 10^{-3}\phi$/day
$k_1 = 5.37 \times 10^{-3}$/day

According to the decay scheme of Tm^{170}, 0.1 of the activity is in the form of 85-kev gammas. So the specific activity is given by

$$a = 600x$$

curie-equivalent-gammas/gram, where

$$x = \frac{k_0}{k_1 - k_0}\,(e^{-k_0 t} - e^{-k_1 t})$$

The maximum specific activity is given by the simple formula

$$a^* = 600e^{-k_1 t^*} = 600e^{-5.37\times10^{-3}t^*}$$

which relates the maximum specific activity to the time required to reach the maximum.

As we have seen, t^* is a function of flux and k_1; actually, for thulium

$$t^* = \frac{-5.37}{5.37 - 1.035\phi}\ln(0.1925\phi)$$

An illuminating graph is obtained by plotting a^* against t^* and spotting sufficient values of ϕ along the curve to permit easy interpolation. The functional form of the a^*, t^* relation indicates that a semilog plot should be used, as this is a straight line. The combined flux, time, activity relations are shown in Fig. 5.

Actual formation curves for several flux values are shown in Fig. 6. From these it is apparent that irradiations can be stopped considerably before the maximum is reached, because the rate of increase is slow as the maximum is approached.

The flux values chosen for these curves are representative of the range of effective fluxes that might be encountered in the MTR.

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Film Badge Dosimetry: How Much Fading Occurs?

Latent-image fading, sometimes large, varies widely with emulsion type. Grave errors in radiation dose vs film density readings can result unless adequate corrections are applied. Semi-empirical equations relating fading to storage time are presented

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LATENT-IMAGE FADING for storage periods up to eight days has been studied for six photographic emulsion types. The results can be described by equations giving fading vs storage time for different exposures of each emulsion. But before the present experiment can be considered, a review of latent-image instability is needed.

Image Instability

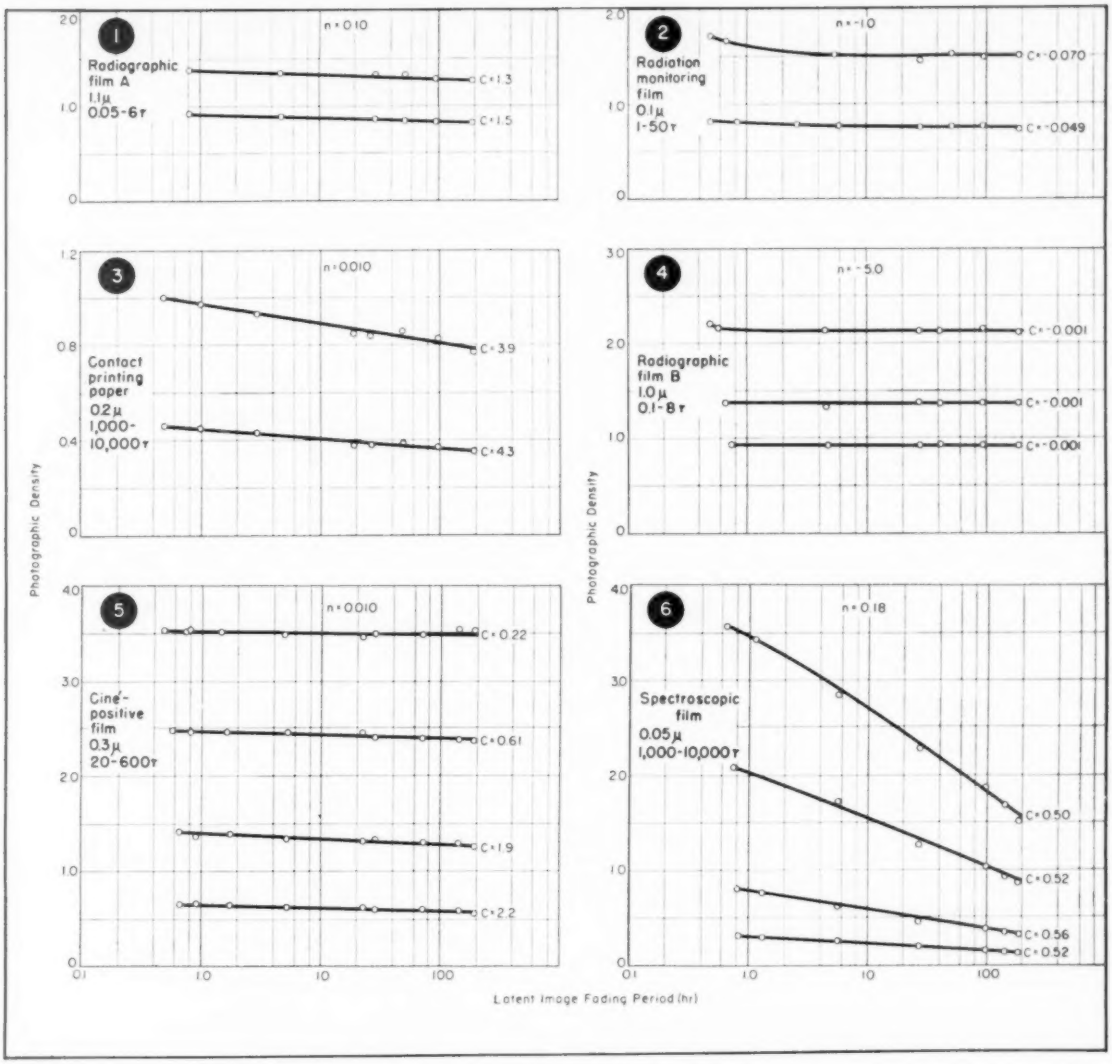
Whether formed by the action of visible light, X- or gamma radiation, or high-energy corpuscular radiations, the photographic latent image is unstable. In some instances a slight growth of the latent image is observed immediately after completion of the exposure; the growth is then followed by a more or less pronounced latent-image fading.

Ever since latent-image growth and fading were first observed (*1*), a considerable amount of speculation has arisen concerning their nature, and by no means has there been agreement on the mechanisms involved. This is probably in part due to the fact that different investigators have worked with different types of emulsions under considerably different circumstances. However, it is now generally agreed that latent-image fading is predominantly a chemical process, initiated by the atmosphere surrounding the emulsion. For example, experiments by Mather on nuclear track emulsions stored *in vacuo* established that for the emulsion studied at least 90% of proton-track fading was caused by the chemical influence of certain atmospheric components (*2*). Beiser subsequently developed a theory attributing at least part of the residual 10% fading *in vacuo* to the thermal (physical) ejection of electrons from the latent image's silver specks (*3*).

The relative importance of chemical and physical causative agents probably differs for various types of emulsions. Explanations on an entirely physical basis have been given for the dose-rate-dependent fading during exposure of emulsions to visible light (low-intensity reciprocity-law failure) (*4*); also for the fact (*5*) that along a single track in a nuclear emulsion more fading occurs at the beginning of the track (low specific ionization) than at the end (high specific ionization).

On the other hand, the chemical nature of at least a large portion of the effect becomes apparent in experiments on the dependence of latent-image fading on the type of processing (*6*, *7*). The chemical nature is also revealed in the latent-image fading increasing with higher atmospheric oxygen and moisture (*5*, *8*, *9*). Decreased fading with higher bromine-acceptor concentrations in the grain's immediate surroundings supports a chemical fading mechanism. Chemical action is also revealed by fading being largely confined to the surface of the emulsion's photosensitive units, increasing sharply with decreasing silver-halide grain size (*7*, *10*) and particularly with size of silver speck development centers within these grains (*11*).

Nuclear track emulsions. Quantitative results obtained by grain-density measurements of nuclear track emulsions lend themselves comparatively well to mathematical formulation. Coppens (*12*) describes his experimental data by an empirical relationship that follows essentially a Gaussian distribution. Beiser (*11*) takes into consideration the physical and chemical nature of the phenomenon. His semi-empirical relations are based on the assumption that the fading rate for any set of constant conditions is proportional to the number of development centers present at



LATENT-IMAGE FADING vs storage period for the six emulsions tested. Approximate average grain size in microns and useful range for Co^{60} gammas is shown for each film

any time. This assumption leads to an exponential decay, the constant in the exponent being dependent upon storage conditions. Beiser then determines this constant with the aid of the laws of reaction kinetics, taking into consideration the temperature dependence of latent-image fading, as well as the effect of surface adsorption of oxygen and water from the surrounding atmosphere.

Demers *et al.* (*9*), working with protons and alpha particles, deduce from their experimental data that the fraction of the original grain density remaining after a time t is proportional to $2^{-(ct)^n}$, where the constant c depends on the specific ionization and the constant n on the relative humidity.

Need for Study

The extensive use of commercial radiographic and photographic film for monitoring X- and gamma radiation necessitates the interpretation of densities in film that has been subjected to extreme conditions of temperature and humidity, and whose processing may be delayed for several days, or even weeks, after exposure. Investigation of commercial radiographic and photographic emulsions by measuring the diffuse optical density of conventionally processed film and quantitative description of the fading process are the objectives of the following sections.

Fading vs Storage Time

Selected for the experiments were some of the commercial emulsion types most generally used in photographic dosimetry. Individual film strips (paper strips for specimen 3) were exposed to X-radiation produced at 150 kv constant potential.

Preliminary studies had revealed that a change from this X-ray source

(with 3-mm aluminum equivalent inherent filtration only), to Co^{60} gamma radiation did not produce measurable changes in fading characteristics. For this reason total exposure was varied for different emulsion types by varying beam filtration, and therefore dose rate, rather than exposure time. This made it possible to use relatively brief exposure times (less than 10 minutes) for exposures within the useful range of each emulsion.

The exposures were given by identical procedure at convenient intervals during an eight-day period, after which time all samples were processed simultaneously and their diffuse transmission densities determined with the aid of a photoelectric densitometer. In processing, Kodak Liquid X-Ray Developer was used for 5 minutes, at 20° C. Between exposure and processing, the samples were stored at room temperature (25.5 ± 1.5° C) and at 42 ± 8% relative humidity. No attempt was made in the present study to determine the change in latent-image characteristics with humidity.

Results. The illustrations on page 35 show the changes in latent image observed in the six tested commercial film types.* Photographic density is plotted as a function of time elapsed between exposure and processing. The points represent the actual experimental data, while the lines were obtained from the empirical relations to be discussed later.

The extent of fading is quite different for the different emulsions; in fact, specimens 2 and 4 show hardly any fading after a short initial fading period, while for the other emulsions, fading remains apparent throughout the observation period. Specimen 6 actually shows a density decrease by about one-half over the eight-day storage period.

* One film type that showed, in a preliminary test, slight initial latent-image growth prior to latent-image fading was omitted from these studies.

It is also interesting to note that while small grain size seems to be a determining factor for latent-image instability, the rate of fading is sometimes larger for a coarser-grained emulsion than for one with considerably finer grain. Specimen 6, which has the finest grains, does show the greatest rate of fading. However, the latent image of specimen 5, which has comparatively fine grains, fades more slowly than that of the largest grained specimen type 1.

Quantitative Formulation

Previous authors derived empirical expressions for the fading of grain densities along nuclear tracks; similar ideas are adopted here for changes of net diffuse transmission densities measured photometrically. Under the assumption that the diffuse transmission density is proportional to the average nuclear-track grain density, and in line with the ideas of Beiser (*11*), the concentration of developed silver specks is set proportional to the diffuse transmission density. According to the exponential-decay law, the fractional decrease in transmission density (fading coefficient) is

$$\frac{D_0 - D(t)}{D_0} = 1 - e^{-ct} \qquad (1)$$

where D_0 is the density for zero-fading time, $D(t)$ is the density at time t after exposure, and c is a constant. Modifying this expression according to Demers *et al.* (*9*), one arrives at

$$\frac{D_0 - D(t)}{D_0} = 1 - e^{-ct^n} \qquad (2)$$

where the constant n depends on emulsion characteristics and storage conditions, and the constant c varies with the initial film density.

Equation 2 was used to describe the observed fading quantitatively. As the specimens were never processed immediately after exposure, the shortest storage time having been 30 minutes, Eq. 2 was used in the form

$$\frac{D(a) - D(t)}{D(a)} = 1 - e^{c(a^n - t^n)} \qquad (3)$$

where the known quantity $D(a)$, which is the density at the time $t = a$, was substituted for the unknown quantity D_0. The values for the constants n and c indicated on the figure were chosen so as to make Eq. 3 fit the experimental data. For specimens 1, 3, 5, and 6 the constant n is positive and is 0.01–0.18. The constant n is negative for the two film specimens for which the semilog plot of density vs fading time has a large initial slope. For all specimens, c increases with decreasing initial film density, but initial density values lying on the toe of the emulsion's characteristic curve do not follow this rule. For specimen 6 the lowest curve actually lies in the toe region. The increase in c expresses the fact that the latent image fades more percentage-wise for low densities (corresponding to low doses) than for high ones, which is in agreement with Lauda's observations (*6*). The fit of the empirical expressions to the experimental data is satisfactory in all instances.

Conclusions

The wide variation in fading coefficient shows the importance of applying adequate corrections when using photographic film for radiation dosimetry. The quantitative formulation of the experimental results shows that it is possible to apply the concepts developed for track fading in nuclear emulsions to fading phenomena in other emulsions as well.

* * *

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When Was This Written?

"It was in 1953 when the first atomic energy induced radio-activity into the sphere of industrial machinery, and its first general use was to replace the steam engine in electrical generating stations."

—H. G. WELLS, in his book "The World Set Free," published in 1913

Does Irradiation Induce Radioactivity in Food?

Negative results obtained with irradiated samples of 24 elements that occur in food indicate that induced radioactivity is no problem in food sterilization. Kilocurie cobalt-60 source provided radiation; precise scintillation counter was used for measurements. Extending this work to include irradiation with higher-energy fission products is suggested to insure absolute safety

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A PREVALENT ASSUMPTION is that X- and gamma rays used for food sterilization and chemical processing induce no radioactivity. This assumption is based on irradiated materials showing no activity when tested with ordinary radiation monitors. But in most cases, small amounts of induced activity could be easily overlooked because background radiation obscures measurements.

Since great effort is being expended on developing food sterilization with gamma radiation, it was felt that some numerical limits for the amounts of induced activity should be determined experimentally. This article is the initial report of such measurements made in an independent experimental program. This program resulted from discussions at the Symposium on Radiation Sterilization of Foods, June 26, 1953, at Massachusetts Institute of Technology. It is not designed to evaluate tolerance limits of various activities in foods, but is limited to determining, within the limits of available detection, the amount of activity induced in a number of elements by gamma rays from cobalt-60 and, later, from gross fission products.

A literature search indicates that X-rays definitely can induce low levels of activity in certain elements. A 4.1-hr indium activity resulting from X-ray excitation was first reported in 1939 (*1*) and was shown to have a threshold of 1.2 ± 0.1 Mev for its production (*2*). Later, it was found that lead (*3*) and silver activities (*4*) could also be produced by X-rays with energies up to 1.5 Mev. Wiedenbeck (*5–7*) studied the excitation of these and other elements, such as rhodium, cadmium, gold, and krypton. In each case, the ground-state isotope was excited to an isomeric state by the X-radiation. The isomer then decayed according to its characteristic half-life and energy, as shown in Table 1 (*8*).

Guth (*9*) has shown that X-ray excitation is a "line absorption," in which X-rays of only a narrow energy range will induce the activity. It was found that the radiation widths of the lowest nuclear activation levels of lead and indium are of the order of a few millivolts. Hence, in the continuous spectrum of 1.5-Mev X-rays, only about 1 in 10^8 X-ray quanta has an energy capable of inducing activity. Guth (*9*) reports that Goldhaber, Hill, and Szilard irradiated indium with the gamma rays from 0.5 gm of radium without producing any activity. Since it is known that the energy of these gamma rays is sufficient to excite the indium, the absence of activity is attributed to the fact that none of the known gamma-ray energies from radium is equal to the energy of the indium activation level. The probability of excitation is therefore small, and Guth concludes that only irradiation by a continuous X-ray spectrum is likely to lead to a line absorption.

The advent of multikilocurie sources of cobalt-60 and eventual megacurie sources of fission products makes available gamma-ray intensities many orders of magnitude greater than that from 0.5 gm of radium. Furthermore, the thickness of these sources tends to "smear" out the energy of the emitted gamma rays so that the gamma-ray energy spectrum is no longer composed of sharp, nearly monoenergetic rays but approaches a continuous spectrum instead. This spectrum should then be nearly as effective in inducing radioactivity as the continuous X-ray spectrum. Indeed, Harbottle (*10*) has recently reported activation of indium and cadmium isomers with cobalt-60 gamma rays.

Equipment for Tests

Even though a slightly less than 10-kilocurie cobalt source was used for the present tests (*11, 12*), the literature indicated that if any activity was induced in a sample it would be low

TABLE 1 — Nuclear Data for Isomers (*8*)

Isomer	*Half-life*	*Radiation*	*Energy of radiation (Mev)*	*Internal conversion coefficient*
Rh^{103m}	57 min	γ	0.040	high
Ag^{107m}	44.3 sec	γ	0.094	$e^-/\gamma \sim 16$
Cd^{111m}	48.6 min	γ	0.150	$e^-/\gamma = 2.3$
			0.246	$e^-/\gamma = 0.064$
In^{115m}	4.50 hr	γ(95%)	0.335	$e^-/\gamma = 0.98$
		β^-(5%)	0.83	
Au^{197m}	7.4 sec	γ	0.130	$e_L^-/\gamma \leq 2.0$
			0.279	$e_L^-/\gamma \sim 0.3$
Pb^{204m}	68 min	γ	0.905	$e^-/\gamma \sim 0.1$
			0.374	$e^-/\gamma \sim 0.05$

TABLE 2 — Trace Elements Contained in 60 lb of Beef (*13*)

Element	*Weight (oz)*	*Element*	*Weight (oz)*
Al	0.00001	Mo	0.000014
B	0.00006	Ni	0.000003
Ca	0.0025	P	1.6
Cr	0.000003	K	4.7
Co	0.000002	Si	0.00006
Cu	0.00043	Ag	0.000013
Fe	0.0306	Na	0.40
Pb	0.00001	Sn	0.000002
Mn	0.00002	Zn	0.045
Mg	0.204		

enough to require a sensitive detector. This would hold even for samples exposed for two weeks at 220,000 rep/hr (about 5×10^{10} photons/cm^2/sec).

In addition, Table 1 indicates that X-activated nuclei usually decay by gamma-ray emission. Thus an ordinary Geiger tube, having a gamma-ray counting efficiency of only about 1% would be ineffective. But an available scintillation well counter had a counting efficiency of about 43% for cobalt-60 gamma rays and about 51% for those of iodine-131.

This well counter consists of a $1\frac{3}{4}$-in. diameter by 2-in. thick crystal of thallium-activated sodium iodide, used with a Dumont 6292 (K-1186) photomultiplier that feeds a scaler and register. A $\frac{3}{4}$-in. hole was drilled $1\frac{1}{2}$-in. deep in the center of the crystal, and the entire crystal was encased in $\frac{1}{32}$-in. aluminum.

Samples were irradiated and counted in test tubes, 1.6 cm. in diameter by 15 cm long that just fit into the counting well. To insure maximum detection sensitivity, at least 2 in. of sample was placed in the test tube so that the well was completely filled.

Because of its large detection area, the counter had a high background counting rate. But enclosing the counter in about 4 in. of lead reduced background to about 300 cpm, giving reasonable statistical precision for 1-hr counts both for background and sample. The "9/10's error" was about 1.2% for such a determination.

Indium Activation

To show that the cobalt-60 source actually could produce gamma-ray activation, indium was irradiated. It was felt that if the source intensity was sufficient to activate anything, it would be indium.

A test tube was filled with about 85 gm of indium and irradiated in a flux position of about 220,000 rep/hr nearly to saturation of the 4.5-hr activity. When counted, the sample showed activity about 40 times the well-counter background.

The activity decayed with 4.41-hr half-life, with a 9/10's reliability factor of 0.05 hr. This value agrees with accepted values for In^{115m}.

A rough attempt to evaluate well-counter efficiency gave a value of about 50% for the In^{115m} gamma rays. Rough evaluation of self-absorption in the indium metal indicates that about 1,000 gamma dpm/gm of indium were formed by irradiation, or roughly 4.5 gamma dpm/gm indium per 1,000 rep/hr saturation flux. Harbottle reports an order-of-magnitude value of 10^{-9} barns as the cross-section of indium for cobalt-60 gamma rays (*10*).

Food-Element Tests

Meat is one product for which radiation sterilization may be particularly well suited. Once the work with indium established that induced activity could be detected, trace elements contained in meat were examined for possible activation.

Mittledorf has calculated the amounts of various trace elements occurring in the 60 lb of beef that he estimates the average American eats a year (*13*); his values are given in Table 2. Pure samples of each of these elements (as well as carbon, oxygen, sulfur, and iodine) were prepared as indicated in Table 3 and subjected to two series of experiments.

In one series, the samples were irradiated simultaneously for about a day and then quickly removed from the source and counted. It was possible by rapid manipulation to have a sample in the well counter 40–45 sec after irradiation. Activities with half-lives as short as 20 sec could have been detected if formed in even one-tenth the yield of indium. But, using 20-min counts, no activity greater than 5% background was found.

In a second set of experiments, samples were irradiated in the high-flux position of the source at a flux level of 220,000 rep/hr for about two weeks. The samples were then removed individually and counted. Results were compared with a background count taken the same day and also with a blank-sample count taken before irradiation. One-hour background counts fluctuated ±1% over the three-week period of the measurements.

Only two samples varied from background by more than ±1%. One was potassium chloride, which gave a count that was two-thirds higher than background. This is attributable to natural radioactivity, since the blank sample gave the same count as the irradiated sample. Increased activity after irradiation was also found in the chromium-metal-powder sample. But since this activity did not decay over a period of several weeks, it was attributed to contamination.

Extension of Tests

These studies substantiate the belief that no detectable radioactivity is induced in 24 elemental food constituents by gamma-ray irradiation with a multikilocurie cobalt-60 source. However, in the method used, radiation must pass through the test tube, about 300

mg/cm², and the aluminum casing of the crystal before it is detected. This prevents detection of gamma rays less energetic than about 30 kev or of most conversion electrons from highly converted gamma rays.

Since early work in this field indicated several elements having isotopes that upon activation decay with such weak radiations, a desirable extension of this work would use a sensitive method for detecting the weakest radiations without self-absorption or container-absorption effects. A relatively large liquid-scintillator volume, like that used in low-level carbon-14 and tritium tracer work (*14–16*), might give the required sensitivity. Chemical problems of dissolving the element and scintillator in a mutual solvent would, however, add difficulties to this approach.

The present study was further limited by use of a cobalt-60 source emitting only 1.33- and 1.13-Mev gamma rays. Commercial methods of food sterilization will probably use gross fission products, with gamma spectra depending on fission-product age and energy of neutrons that produced the fission. The contribution of radiations from particular fission-product isotopes has been presented as a function of age for U^{235} thermal-neutron fission by Hunter and Ballou (*17*). From their work, it can be assumed that many of the gamma rays will have energies equal to or lower than those of cobalt-60. But small percentages of higher-energy gamma rays may be present after fission products have aged a few weeks or months. Thus the energy spectrum of "thick" fission-product sources could start at an energy much higher than the cobalt spectrum.

Since the early X-ray work showed that a number of elements could be excited by energies between 1.5 and 3.0 Mev, the experiments reported here should be repeated with kilocurie or larger fission-product sources.

In any food activation study, other sources of sample activity must be considered. One of the elements tested here, potassium, has a low-abundance isotope that is naturally radioactive and detectable with our apparatus.

Natural radium also often occurs to a small extent in many materials. Shandley (*18*) has reported a highly sensitive method for determining radium content of common foods by de-emanation. He found that most foods tested fell within the range of 0.74 to 6.5 $\times 10^{-15}$ gm radium per gm of starting material. This amounts to about 10^{-9} microcurie of radium or about 2×10^{-3} dpm/gm of food.

In the present study, use of high-purity samples reduced the possibility of such contamination. In addition, careful background blank counts were taken on each sample and compared with sample activity after irradiation.

* * *

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TABLE 3—Form, Source, and Weight of Test Samples

Element	*Form*	*Source*	*Weight* (gm)*	*Remarks*
Aluminum	Powder	Alcoa	2.7	High purity
Boron	Powder		4.8	Student prep.; small amt. of chem. contamination
Calcium	Metal turning	B & A	2.1	Reagent grade
Carbon	Graphite flakes	Fisher	2.9	
Chromium	Metal powder	Charles Hardy	15.1	
Cobalt	Metal powder	Old Kahlbaum material	5.9	Contains some chloride
Copper	Metal pellets		16.3	Standard laboratory grade
Iron	Metal powder		12.2	Standard laboratory grade
Iodine	Crystals	Mallinckrodt	11.0	Analytical reagent
Lead	Metal findings	Mallinckrodt	21.5	Analytical reagent
Magnesium	Metal powder	Dow	5.5	High purity
Manganese	Metal powder	Charles Hardy	15.1	
Molybdenum	Metal powder	Primus Chemical Co. (1912)	14.5	
Nickel	Metal shot	Mallinckrodt	16.1	Analytical reagent
Oxygen	Al_2O_3	Harshaw	5.3	
Phosphorus	$(NH_4)_2HPO_4$	Mallinckrodt	3.7	Analytical reagent
Potassium	KCl	General Chemical Co.	5.3	Reagent grade
Silicon	Powder	Fairmount Chemical Co.	4.0	
Silver	Metal powder	G. Frederick Smith	16.0	Reagent grade
Sodium and chloride	NaCl	Merck	5.9	Analytical reagent
Sodium and fluoride	NaF		3.3	C.P.
Sulfur	Roll		4.38	Cast
Tin	Metal granules	General Chemical Co.	15.1	Reagent grade
Zinc	Metal granules		10.6	C.P.

* Listed weight is the amount of material contained in the bottom cm of the test tube used in the irradiation.

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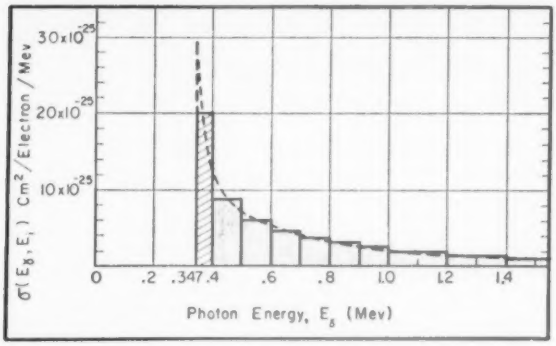

FIG. 1 Cross section for the production of 0.2-Mev Compton electrons

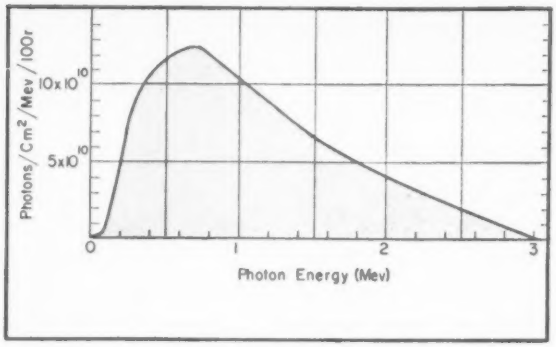

FIG. 2 Theoretical photon distribution produced by a filtered 3-Mev X-ray machine, normalized to correspond to a dose of 100 r

Electron Energy Distributions Produced by Gamma-Rays

Here are tables that enable one to calculate the distribution of secondary-electron energies in gamma-ray irradiated materials. Applications to cavity measurements of ionization and to radiological problems are discussed

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A DETAILED KNOWLEDGE of the number and energies of the electrons set in motion in a material when it is irradiated by a continuous spectrum of X-rays is very useful. Calculations of energy abstracted from the beam and absorbed by the material, and of the ionization produced in a cavity within the material, all depend on such knowledge. Applications of these calculations are described elsewhere (*1–4*).

Tables are presented that make it possible to calculate the initial energy distribution of the electrons set in motion in an element of volume by either monoenergetic radiation or continuous spectra.

After being set in motion, these electrons of differing energy proceed out of the volume in which they originated and travel through the absorbing material, losing energy at a varying rate, until they are brought to rest. It is useful to be able to determine the electron flux passing through an element of area at any point in the material. From the initial volume distribution, the energy distribution of electrons passing through an element of area is calculated in this article.

Initial Distribution

Electrons are set in motion in γ-ray-irradiated material by Compton effect, pair and triplet production, and photoelectric effect. Two sets of tables presented here give the energy distribution, $N(E_i)\,dE_i$, of electrons set in motion by these processes. One set of tables is for monoenergetic γ-rays, the other for a continuous spectrum of radiation. The γ-ray energy scale is in three ranges: 0–300 kev, the normal X-ray generator range; 0–4 Mev, accessible with electrostatic generators; and 0–30 Mev, the domain of betatrons and linear accelerators.

All tables give the cross section per electron of the absorbing material.

Monoenergetic radiation. The first row of Tables 1, 2, and 3 gives the discrete photon energies; the first column, the chosen electron-energy intervals. The values in the body of the table give the cross section per electron for it to be set in motion with energy in the indicated interval.

For example, from Table 1, one 180-kev photon per cm^2 will, by the Compton process, set 45.5×10^{-27} electrons in motion with energies between 30 and 40 kev per electron of the material. To find the number produced per cm^3 one multiplies this figure by the number of photons per cm^2 and the number of electrons per cm^3 of material, which for water is 3.34×10^{23}.

The maximum energy a photon can give an electron is shown in the first

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line under the corresponding photon energy. For example, 100-kev photons cannot produce Compton electrons of more than 28.1 kev.

Photoelectric cross sections for water are given in the bottom line. The energy of the photoelectron is the photon energy less the binding energy. Usually the binding energy can be neglected for low-atomic-number materials; this has been done here.

Continuous radiation spectrum. Data suitable for calculating the initial electron distribution produced by a continuous spectrum of radiation are given in Tables 4–6.

The values in the main body of each table give the number of electrons set in motion per Mev interval at the electron energy shown in the first line by 1 photon per cm² per Mev interval in the energy interval shown in the first column.

A simple example will illustrate the use of Tables 4, 5 and 6. Suppose one requires the number of electrons in the range 5.9–6.1 kev produced in a cm³ of water by 3×10^7 photons/cm² in the range 100 to 120 kev. This is equivalent to 1.5×10^9 photons/Mev interval. The electron energy interval 5.9 to 6.1 kev is $\frac{1}{5,000}$ of an Mev interval. Hence the number required is $3.34 \times 10^{23} \times 32.5 \times 10^{-26} \times 1.5 \times 10^9 \times \frac{1}{5,000} = 3.26 \times 10^4$ Compton electrons/cm³.

At the bottom of Table 4, photoelectric cross sections are given. The photon energy corresponding to each of the values entered is the electron energy at the top of the column plus the suitable electron binding energy.

The procedure to be followed in finding the initial electron distribution for a continuous γ-ray spectrum will now be illustrated. The γ-ray spectrum of Fig. 2 will be used as an example; it is approximately the distribution produced by a 3-Mev machine filtered with 10 mm of lead and 5 mm of copper (4). A tabular method is recommended and is illustrated in Table 7.

The photon energy intervals (corresponding to those of Table 5a) are given in the first column. The number of photons/cm²/Mev interval taken from Fig. 2 are listed in the second column. Since most photon distributions do not vary rapidly with energy, the average number of photons per Mev for an energy interval can usually be taken as the value at the midpoint

Data for Computing Initial Electron Energy Distributions

TABLE 1—E_γ = 0–300 kev, Compton Electrons

Electron energy interval (kev)	Photon energy, E_γ (kev)														
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
	Maximum electron energy (kev)														
	1.45	5.42	11.4	19.1	28.1	38.4	49.6	61.8	74.5	87.8	102	116	131	146	162
0 – 10	616	578	546	277	198	148	115	90.8	73.7	59.6	50.3	42.7	36.5	31.8	27.5
10 – 20				240	138	105	86.3	73.2	62.1	52.2	45.0	38.8	33.8	29.7	26.0
20 – 30					157	96.6	71.0	60.1	52.0	45.3	39.8	35.1	31.0	27.6	24.4
30 – 40						121	74.3	53.7	45.5	39.9	35.6	31.8	28.4	25.6	22.9
40 – 50							106	58.4	42.8	36.2	32.1	29.0	26.2	23.7	21.5
50 – 60								100	47.0	35.4	30.1	26.8	24.2	22.1	20.1
60 – 70									61.6	38.8	29.9	25.5	22.8	20.7	19.0
70 – 80									36.7	48.3	32.4	25.5	21.8	19.7	18.0
80 – 90										50.5	38.7	27.3	21.9	19.2	17.3
90 – 100											60.6	31.5	23.2	19.1	16.9
100 – 110												39.4	26.2	20.0	16.9
110 – 120												30.6	31.6	22.2	17.5
120 – 130													40.7	25.9	19.0
130 – 140														31.6	21.6
140 – 150														24.6	25.7
150 – 160															39.1
Total Compton (per electron)	616	578	546	517	493	471	453	436	421	406	394	384	368	364	353
Photoeffect in water (per electron)	1420	148	39	15	7.1	3.9	2.4	1.6	1.1	0.77	0.57	0.43	0.33	0.37	0.21

Number of Compton electrons set in motion per electron of material per photon per cm²

Multiply table values by 10^{-27}

TABLE 2a—E_γ = 0–4 Mev, Compton Electrons

Electron energy interval (Mev)	Photon energy, E_γ (Mev)																
	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.5	3.0	3.5	4.0
	Maximum electron energy (Mev)																	
	0.0281	0.0878	0.162	0.244	0.331	0.421	0.606	0.796	0.989	1.18	1.38	1.58	1.77	1.97	2.27	2.76	3.26	3.76
0 – 0.2	493	406	353	242	166	122	73.4	48.4	34.3	25.3	19.7	15.8	12.6	10.5	8.13	5.65	4.13	3.18
0.2 – 0.4				75.2	123	146	64.6	44.4	32.3	24.2	19.0	15.3	12.3	10.3	8.03	5.60	4.10	3.17
0.4 – 0.6							96.6	45.0	31.7	23.8	18.6	14.9	12.2	10.2	7.96	5.58	4.09	3.16
0.6 – 0.8							73.4	36.0	24.9	18.9	14.9	12.3	10.3	7.99	5.59	4.10	3.17	
0.8 – 1.0								59.0	30.4	20.6	15.8	12.8	10.5	8.12	5.63	4.12	3.18	
1.0 – 1.2									49.4	26.5	17.9	13.8	11.0	8.39	5.75	4.18	3.20	
1.2 – 1.4										42.5	23.4	15.9	12.1	8.85	5.94	4.26	3.24	
1.4 – 1.6											37.4	21.1	14.4	9.70	6.22	4.38	3.31	
1.6 – 1.8												33.4	19.3	11.4	6.63	4.57	3.40	
1.8 – 2.0													29.9	14.6	7.36	4.83	3.54	
2.0 – 2.2														35.5	8.59	5.21	3.70	
2.2 – 2.4															10.6	5.77	3.93	
2.4 – 2.6															14.9	6.63	4.24	
2.6 – 2.8															21.1	8.08	4.67	
2.8 – 3.0																10.7	5.34	
3.0 – 3.2																24.7	6.38	
3.2 – 3.4																	8.12	
3.4 – 3.6																	11.6	
3.6 – 3.8																	15.5	
Total Compton (per electron)	493	406	353	317	289	268	235	211	193	178	166	155	146	138	129	115	104	96.0

Number of Compton electrons set in motion per electron of material per photon per cm²

Multiply table values by 10^{-27}

TABLE 2b—E_γ = 0–4 Mev, Pair Electrons

Electron energy interval (Mev)	Photon energy, E_γ (Mev)									
	1.2	1.4	1.6	1.8	2.0	2.2	2.5	3.0	3.5	4.0
	Maximum electron energy (Mev)									
	0.178	0.378	0.578	0.778	0.978	1.18	1.48	1.98	2.48	2.98
0–0.2	0.08	0.20	0.25	0.30	0.32	0.34	0.32	0.31	0.29	0.28
0.2–0.4		0.18	0.36	0.48	0.56	0.59	0.62	0.62	0.60	0.57
0.4–0.6			0.21	0.48	0.60	0.66	0.72	0.75	0.74	0.71
0.6–0.8				0.25	0.55	0.66	0.76	0.82	0.82	0.80
0.8–1.0					0.26	0.57	0.74	0.85	0.86	0.85
1.0–1.2						0.27	0.67	0.85	0.88	0.88
1.2–1.4							0.49	0.81	0.88	0.89
1.4–1.6							0.06	0.74	0.87	0.90
1.6–1.8								0.60	0.84	0.89
1.8–2.0								0.25	0.77	0.88
2.0–2.2									0.66	0.84
2.2–2.4									0.45	0.79
2.4–2.6									0.06	0.70
2.6–2.8										0.56
2.8–3.0										0.23
Twice total pair (per electron)	0.08	0.38	0.82	1.51	2.29	3.09	4.38	6.60	8.72	10.8

Number of electrons (+ and −) set in motion per electron of material per photon per cm²

Multiply table values by 10^{-27}

Cross Section Calculations

Comprehensive discussions of the Compton, photoelectric and pair processes have been given by White (5) and Davisson and Evans (6). Our tables were derived from this basic information. The tabulated values are estimated to be accurate to about 1%.

Compton effect. *Differential cross sections for a given photon energy were plotted against the electron energy from data tabulated in reference (7) and integrated graphically over the electron energy intervals shown in the first columns of Tables 1, 2a and 3a, to yield the data presented in those tables. The sums of the vertical columns give Compton absorption cross sections that agree with those tabulated by White (5).*

The data in Tables 4, 5a and 6a were obtained by plotting the differential cross section for a given electron energy as a function of the photon energy. These were integrated both mathematically and graphically over the photon energy intervals shown in the first columns of Tables 4, 5a and 6a, to yield the data of these tables.

For example, in Fig. 1 the differential cross section for production of 0.2-Mev electrons has been plotted against photon energy. The photon energy scale has been broken up into a series of bands 0.1 Mev wide corresponding to the intervals of the first column of Table 5a. The smooth cross-section curve can be replaced by a histogram as indicated. The area in each rectangular section is equal to the area under the smooth cross-section curve and has been entered in Table 5a.

A slight refinement of this process was made in Table 4, where the S correction for small momentum transfer from photon to electron, (5, 8), was applied. The correction ranges from 0.91 to 1.0 as the electron energy is increased from 0.5 to 6 kev. Had this correction been neglected, the number of low-energy electrons would have been overestimated.

The Compton tables may be used for materials other than water since the cross section per electron is independent of Z. This neglects the fact that the S correction is a function of Z, but this correction and the error are small.

Pair production. *The Bethe-Heitler formula (9) for the differential-pair-production cross section was evaluated and corrected for screening (6) by water molecule electrons. Triplet production, which amounts to about 10% of the pair-production contributions above its $4m_0c^2$ threshold, was accounted for using Borsellino's values (10). The triplet energy distribution was assumed the same as for pairs.*

Tables 2b and 3b and Tables 5b and 6b were computed from these cross sections in the same manner as the corresponding tables for Compton electrons. Both positrons and negatrons were counted; hence the sum of the vertical columns gives twice the pair-production cross section. Values agree with White's.

Pair-production cross sections per electron depend approximately on the first power of Z. Table values are for water, but may be used for other materials by multiplying by (Z/6.60) since the effective atomic number for pair production in water is 6.60. The method of calculating the effective Z for other materials has been discussed elsewhere (1).

Above 8 Mev small errors are introduced in the conversion because of the dependence of the screening on atomic number. At 30 Mev, the value obtained for aluminum from Table 6b would be 6% too high. However, for low-atomic-number materials ($Z < 10$) the error in using the conversion factor is not serious.

Photoelectric effect. *The cross sections for the photoelectric effect in water were obtained from White (5) for high photon energies, and from Allen's data (11) for low energies. Values for other materials may be obtained directly from White.*

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of that interval. The product of these numbers and the values of Table 5a are entered in Table 7 under the appropriate electron energies. All products were multiplied by the number of electrons per cm³ of water. The sum of vertical columns gives the number of electrons per cm³ of water per Mev interval.

There is one complication: corresponding to each electron energy there will be one γ-ray energy interval that includes the minimum γ-ray energy capable of producing a Compton electron of that energy. For example, 0.2-Mev electrons cannot be produced in Compton processes where the energy of the incident γ-ray is below 0.347 Mev, as is illustrated in Fig. 1. In computing the contribution to the number of 0.2-Mev electrons by γ-rays in the 0.3–0.4-Mev interval, one should take account of this fact by using the number of photons per cm² per Mev at 0.373 Mev, that being the midpoint of the 0.347–0.40-Mev sub-interval that is actually capable of producing 0.2-Mev electrons.

Values of the true center of each of these "lowest energy" intervals are given in italics in Tables 4–6 directly above the cross section entry with which they are associated.

Using the foregoing tabular method one finds that the total number of 0.2-Mev electrons produced is 18.1×10^9. This value can be obtained by taking the point-by-point product of the smooth differential cross section curve (Fig. 1) and the photon distribution curve (Fig. 2) and finding the area under the resultant curve. In practice the tabular method is likely to be more accurate and easier to carry out. The only error introduced by the tabular method is in assuming that the average number of photons per Mev in an interval is the number corresponding to the midpoint.

The total number of electrons of each energy have been plotted versus electron energy in Fig. 3, curve a. The points lie on a smooth curve and are the exact values for the corresponding electron energies; they are not the average value over a range. The only averaging process carried out was in obtaining the number of photons per energy interval from Fig. 2. In our former work, difficulty in obtaining a smooth curve such as in Fig. 3 was experienced because of the large contributions to the cross section at the peaks of the Compton curves.

In this example only the Compton effect need be considered since the contribution from other processes is small. If the pair process must be included, a table similar to Table 7 should be prepared for pair electrons and the energy distribution added.

Electron Flux

The energies of the electrons passing through an element of area in the material can be obtained from the initial volume distribution (3).

Consider an element of volume ΔV, $1 \times 1 \times \Delta x$ cm, at the point Q in Fig. 4. The number of electrons set in motion in this volume with initial energies greater than E is

$$K = \left(\int_E^{E_{i\,max}} N(E_i)\, dE_i \right) \Delta x$$

where $N(E_i)\,dE_i$ is the number set in motion per cm³ with energies in the interval E_i to $(E_i + dE_i)$.

K also gives the number of electrons coming to rest in the volume ΔV, which originally had energies greater than E, provided equilibrium conditions exist over a distance equal to the range of the maximum-energy electron. The existence of equilibrium makes the following simplified calculation of electron flux possible.

Consider the electron flux at P, Fig. 4, which is distance R in front of Q, where R is the range of an electron of energy E. Electrons that come to rest in ΔV must have passed through the area at P with energies in the range E to $E - \Delta E$. Hence K is the number of electrons that pass through the cm² at P, with energies in the range E to $E - \Delta E$. The number of electrons that pass through a cm² in the material with energy E per unit energy interval is therefore K divided by $-\Delta E$.

This electron flux density will be denoted by $N(E)$ and is given by

$$N(E) = \frac{1}{(-\Delta E/\Delta x)_E}\int_E^{E_{max}} N(E_i)\,dE_i$$

$$= \frac{1}{S(E)^{total}}\int_E^{E_{max}} N(E_i)\,dE_i \quad (1)$$

where $S(E)^{total}$ is the energy loss per cm path of an electron of energy E, due to collisional and radiative processes; it is a function of the atomic number, Z of the material. In Table 8, the total energy loss per cm of path is given for electrons in water.

Table 9 shows how electron flux distribution for spectrum of Fig. 2 was calculated. The first column gives intervals of initial electron energy. Values of $N(E_i)$ from Table 7 were used in second-column calculation. Summing $N(E_i)\Delta E_i$ from E to maximum energy $E_{i\,max}$, we evaluate integral in Eq. 1; third column gives results. Shaded area of Fig. 3, curve a, shows graphical evaluation of integral. $N(E)$ is obtained by dividing by total stopping power (fourth column) to give sixth column and curve b, Fig. 3.

Applications

The distribution of electron energies per unit volume, $N(E_i)$, and among the electrons crossing any area, $N(E)$, can be used in a number of applications.

Energy locally absorbed. For many calculations one can determine the γ-ray energy locally absorbed by assuming that all the energy passed on to the electrons is in turn absorbed locally. This is generally true for electrons of energy up to about 1 Mev, radiation losses being negligible. The energy locally absorbed per cm³ is

$$E_1 = \int_0^{E_{i\,max}} N(E_i)E_i\,dE_i \quad (2)$$

Under this circumstance of negligible radiation loss, the energy locally absorbed can more readily be obtained

TABLE 3a—E_γ = 0-30 Mev, Compton Electrons

Electron energy interval	Photo energy, E_γ (Mev)																	
	1	2	3	4	5	6	8	10	12	14	16	18	20	22	24	26	28	30
	Maximum electron energy (Mev)																	
(Mev)	0.796	1.77	2.76	3.76	4.76	5.76	7.75	9.75	11.8	13.8	15.8	17.8	19.8	21.8	23.8	25.8	27.8	29.8
0 – 1	211	62.2	28.1	15.9	10.1	7.07	3.97	2.55	1.77	1.29	0.990	0.785	0.636	0.528	0.445	0.380	0.328	0.284
1 – 2		84.2	31.9	16.5	10.4	7.20	4.01	2.57	1.78	1.30	0.993	0.786	0.637	0.528	0.445	0.380	0.328	0.284
2 – 3			55.1	21.9	11.9	7.76	4.15	2.62	1.80	1.31	1.00	0.788	0.640	0.530	0.446	0.381	0.329	0.284
3 – 4				41.7	17.0	9.40	4.48	2.72	1.84	1.33	1.01	0.791	0.644	0.533	0.448	0.383	0.330	0.285
4 – 5					33.4	14.1	5.13	2.92	1.92	1.37	1.03	0.801	0.652	0.539	0.450	0.386	0.331	0.286
5 – 6						27.7	6.57	3.26	2.05	1.43	1.06	0.820	0.662	0.547	0.456	0.389	0.333	0.288
6 – 7							10.5	3.88	2.26	1.52	1.11	0.847	0.678	0.556	0.463	0.394	0.336	0.290
7 – 8							21.1	5.11	2.60	1.64	1.17	0.885	0.698	0.570	0.472	0.400	0.340	0.293
8 – 9								8.37	3.15	1.84	1.26	0.931	0.725	0.586	0.484	0.407	0.346	0.297
9 – 10								17.0	4.25	2.14	1.38	0.992	0.760	0.606	0.497	0.415	0.352	0.301
10 – 11									7.00	2.65	1.56	1.08	0.803	0.633	0.513	0.426	0.360	0.307
11 – 12									14.2	3.61	1.84	1.19	0.863	0.665	0.532	0.440	0.370	0.314
12 – 13										6.02	2.29	1.36	0.939	0.706	0.560	0.456	0.382	0.322
13 – 14										12.3	3.14	1.61	1.05	0.761	0.590	0.476	0.396	0.331
14 – 15											5.24	2.01	1.20	0.834	0.630	0.501	0.413	0.342
15 – 16											10.8	2.78	1.43	0.937	0.684	0.533	0.433	0.356
16 – 17												4.66	1.81	1.08	0.755	0.571	0.457	0.373
17 – 18												9.69	2.51	1.30	0.852	0.622	0.486	0.393
18 – 19													4.23	1.64	0.991	0.690	0.524	0.417
19 – 20													8.67	2.28	1.19	0.780	0.571	0.445
20 – 21														3.87	1.51	0.914	0.636	0.482
21 – 22														7.86	2.11	1.10	0.720	0.528
22 – 23															3.58	1.40	0.843	0.588
23 – 24															7.14	1.95	1.01	0.667
24 – 25																3.32	1.30	0.777
25 – 26																6.54	1.81	0.943
26 – 27																	3.09	1.20
27 – 28																	6.08	1.68
28 – 29																		2.87
29 – 30																		5.77
Total Compton (per electron)	211	146	115	96.0	82.8	73.2	59.9	51.0	44.6	39.8	35.9	32.8	30.2	28.1	26.2	24.6	23.2	22.0

Number of Compton electrons set in motion per electron of material per photon per cm²

Multiply table values by 10^{-27}

TABLE 3b—E_γ = 0-30 Mev, Pair Electrons

Electron energy interval	Photon energy, E_γ (Mev)																	
	2	3	4	5	6	8	10	12	14	16	18	20	22	24	26	28	30	
	Maximum electron energy (Mev)																	
(Mev)	0.878	1.98	2.98	3.98	4.98	6.98	8.98	11.0	13.0	15.0	17.0	19.0	21.0	23.0	25.0	27.0	29.0	
0 – 1	2.29	3.45	3.37	3.11	2.83	2.35	2.00	1.75	1.59	1.45	1.33	1.23	1.13	1.04	0.97	0.89	0.83	
1 – 2		3.25	4.65	4.61	4.38	3.88	3.46	3.08	2.77	2.52	2.31	2.13	1.99	1.84	1.73	1.63	1.53	
2 – 3			3.12	4.61	4.58	4.19	3.81	3.45	3.16	2.89	2.66	2.47	2.32	2.18	2.05	1.95	1.84	
3 – 4				2.85	4.38	4.26	3.89	3.57	3.29	3.04	2.82	2.62	2.46	2.32	2.20	2.11	2.01	
4 – 5					2.56	4.19	3.91	3.60	3.34	3.11	2.90	2.71	2.55	2.41	2.28	2.18	2.09	
5 – 6						3.86	3.86	3.60	3.34	3.12	2.93	2.75	2.60	2.46	2.33	2.22	2.14	
6 – 7						2.12	3.81	3.60	3.34	3.12	2.93	2.76	2.61	2.47	2.34	2.24	2.15	
7 – 8							3.44	3.57	3.34	3.11	2.92	2.75	2.60	2.47	2.35	2.24	2.16	
8 – 9							1.80	3.45	3.34	3.12	2.91	2.74	2.59	2.46	2.35	2.24	2.16	
9 – 10								3.07	3.29	3.12	2.92	2.74	2.58	2.45	2.34	2.23	2.15	
10 – 11								1.58	3.16	3.11	2.93	2.74	2.58	2.44	2.33	2.22	2.14	
11 – 12									2.76	3.04	2.93	2.75	2.58	2.44	2.32	2.22	2.13	
12 – 13									1.43	2.89	2.90	2.76	2.59	2.44	2.32	2.21	2.13	
13 – 14										2.51	2.82	2.75	2.60	2.45	2.32	2.21	2.12	
14 – 15										1.30	2.66	2.71	2.61	2.46	2.33	2.21	2.12	
15 – 16											2.30	2.62	2.60	2.47	2.34	2.22	2.12	
16 – 17											1.19	2.47	2.55	2.47	2.35	2.22	2.13	
17 – 18												2.12	2.46	2.46	2.35	2.23	2.13	
18 – 19												1.08	2.32	2.41	2.34	2.24	2.14	
19 – 20													1.98	2.32	2.33	2.24	2.15	
20 – 21													0.99	2.18	2.28	2.24	2.16	
21 – 22														1.83	2.20	2.22	2.16	
22 – 23														0.91	2.05	2.18	2.15	
23 – 24															1.72	2.11	2.14	
24 – 25															0.84	1.95	2.09	
25 – 26																1.62	2.01	
26 – 27																0.77	1.84	
27 – 28																	1.52	
28 – 29																	0.71	
Twice total pair (per electron)	2.29	6.70	11.1	15.2	18.7	24.8	30.0	34.3	38.2	41.4	44.4	46.9	49.3	51.4	53.4	55.2	57.2	

Number of electrons (+ and –) set in motion per electron of material per photon per cm²

Multiply table values by 10^{-27}

TABLE 4 — E_γ = 0–300 kev, Compton Electrons

Photon energy interval (kev)	Electron energy (kev) 0.5	1.0	2.0	4.0	6.0	8.0	10.0	12.0	15.0	20.0	30.0	40.0	50.0	60.0	80.0	100	120	140	160	180
0 – 10	15.8	18.2																		
10 – 20	516	171	26.8																	
20 – 30	240	230	145	37.0																
30 – 40	151	135	109	84.1	46.1	49.7														
40 – 50	103	93.1	74.6	68.7	61.5	6.14														
							57.9													
50 – 60	71.1	67.6	57.9	46.0	43.7	57.0	28.1	70.8	74.9											
60 – 80	90.6	90.2	82.8	67.7	58.1	56.3	61.6	65.5	36.6	91.1										
80 – 100	56.1	56.7	54.3	48.2	42.7	37.8	34.7	33.1	34.7	41.3										
											112									
100 – 120	37.8	38.6	37.7	35.2	32.5	29.8	27.2	25.3	23.2	22.4	26.8	132								
120 – 140	27.2	28.0	27.7	26.5	25.1	23.5	21.9	20.6	18.8	16.8	16.8	20.8	150	159						
140 – 160	20.5	21.1	21.1	20.5	19.8	18.8	17.9	17.0	15.8	14.1	12.2	13.4	18.6	2.78						
160 – 180	16.0	16.5	16.6	16.3	15.9	15.3	14.7	14.1	13.4	12.1	10.2	9.56	10.5	14.3	194					
180 – 200	12.8	13.3	13.4	13.3	13.0	12.6	12.2	11.8	11.3	10.4	8.91	7.99	7.75	8.61	7.83					
																219				
200 – 220	10.5	10.9	11.0	10.9	10.8	10.5	10.3	10.0	9.65	9.07	7.95	7.06	6.58	6.52	8.74	1.65				
220 – 240	8.75	9.08	9.20	9.21	9.10	8.92	8.72	8.54	8.28	7.87	7.07	6.37	5.84	5.56	5.97	9.08	252			
240 – 260	7.41	7.70	7.81	7.82	7.77	7.64	7.51	7.38	7.19	6.89	6.29	5.73	5.24	4.92	4.71	5.77	6.44	276		
260 – 280	6.35	6.60	6.71	6.74	6.71	6.61	6.52	6.43	6.29	6.05	5.60	5.16	4.74	4.44	4.09	4.32	5.73	3.29	299	
280 – 300	5.51	5.73	5.83	5.86	5.85	5.78	5.71	5.63	5.52	5.34	5.00	4.66	4.32	4.07	3.69	3.59	4.14	5.73	0.939	
Photoeffect in water (per electron)			2×10^5	2.4×10^4	6.8×10^3	2.7×10^3	1.3×10^3	730	360	142	38.5	14.8	7.0	3.9	1.50	0.71	0.39	0.24	0.16	0.11

Number of Compton electrons set in motion per Mev interval per electron of material per photon per cm^2 per Mev interval

Multiply table values by 10^{-26}

TABLE 5a — E_γ = 0.4 Mev, Compton Electrons

Photon energy interval (Mev)	Electron energy (Mev) 0.02	0.05	0.10	0.20	0.30	0.40	0.60	0.80	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.5	3.0	3.5
0 – 0.05	0.0911																	
0.05 – 0.10	41.3	0.145																
0.10 – 0.15	47.7	10.8																
0.15 – 0.20	28.3	26.1	0.259															
0.20 – 0.30	35.2	26.7	24.4	0.373														
0.30 – 0.40	19.4	16.8	13.6	9.96	0.482													
0.40 – 0.50	12.1	11.2	9.61	8.92	5.07													
						0.589												
0.50 – 0.60	8.24	7.77	7.07	6.06	7.39	2.68												
0.60 – 0.70	5.93	5.69	5.32	4.72	4.58	6.54	0.797											
0.70 – 0.80	4.45	4.32	4.15	3.79	3.55	3.84	0.560											
0.80 – 0.90	3.45	3.40	3.28	3.05	2.90	2.90	5.40											
0.90 – 1.0	2.78	2.75	2.65	2.52	2.42	2.37	3.00											
								1.10										
1.0 – 1.2	4.16	4.10	4.04	3.86	3.78	3.68	3.97	6.81	1.30									
1.2 – 1.4	2.96	2.96	2.92	2.84	2.78	2.74	2.80	3.27	5.55	1.57								
1.4 – 1.6	2.22	2.18	2.15	2.14	2.13	2.12	2.13	2.26	2.82	4.63	1.71							
1.6 – 1.8	1.75	1.73	1.71	1.69	1.68	1.68	1.68	1.72	1.91	2.52	4.05	1.91						
1.8 – 2.0	1.43	1.42	1.41	1.39	1.37	1.36	1.36	1.38	1.47	1.70	2.24	3.55						
														2.12				
2.0 – 2.2	1.16	1.15	1.15	1.14	1.12	1.12	1.12	1.14	1.18	1.29	1.51	2.03	3.12	2.32				
2.2 – 2.4	0.968	0.962	0.956	0.947	0.940	0.949	0.950	0.964	0.979	1.03	1.15	1.38	1.90	2.83	2.52			
2.4 – 2.6	0.819	0.813	0.809	0.804	0.799	0.795	0.796	0.810	0.824	0.859	0.925	1.04	1.28	1.79	2.57	2.77		
2.6 – 2.8	0.701	0.698	0.694	0.691	0.687	0.685	0.685	0.694	0.707	0.730	0.768	0.840	0.962	1.17	1.65	1.12		
2.8 – 3.0	0.607	0.605	0.602	0.600	0.596	0.596	0.596	0.600	0.608	0.627	0.652	0.701	0.768	0.880	1.10	2.01		
3.0 – 3.2	0.532	0.529	0.527	0.525	0.523	0.522	0.520	0.522	0.528	0.544	0.561	0.592	0.636	0.708	0.826	1.20	3.32	
3.2 – 3.4	0.468	0.467	0.466	0.465	0.462	0.460	0.458	0.460	0.464	0.478	0.488	0.510	0.540	0.586	0.660	0.862	1.91	
3.4 – 3.6	0.415	0.414	0.414	0.413	0.411	0.410	0.409	0.410	0.414	0.422	0.430	0.446	0.468	0.499	0.546	0.661	1.30	3.77
3.6 – 3.8	0.372	0.372	0.371	0.371	0.370	0.368	0.367	0.368	0.371	0.376	0.383	0.396	0.411	0.436	0.467	0.540	0.874	0.748
3.8 – 4.0	0.335	0.335	0.335	0.334	0.333	0.332	0.331	0.332	0.335	0.338	0.344	0.354	0.366	0.385	0.407	0.457	0.656	1.52

Number of Compton electrons set in motion per Mev interval per electron of material per photon per cm^2 per Mev interval

Multiply table values by 10^{-26}

TABLE 5b — E_γ = 0.4 Mev, Pair Electrons

Photon energy interval (Mev)	Electron energy (Mev) 0.02	0.05	0.10	0.20	0.30	0.40	0.60	0.80	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.5
	1.12	1.14	1.16													
1.0 – 1.2	0.019	0.029	0.014	1.37	1.36											
1.2 – 1.4	0.066	0.125	0.144	0.114	0.038	1.57										
1.4 – 1.6	0.096	0.184	0.251	0.304	0.288	0.200	1.77									
1.6 – 1.8	0.107	0.213	0.317	0.405	0.429	0.424	0.249	1.91								
1.8 – 2.0	0.106	0.225	0.349	0.464	0.523	0.542	0.516	0.265								
									2.11							
2.0 – 2.2	0.098	0.223	0.359	0.502	0.579	0.619	0.632	0.564	0.271	2.31						
2.2 – 2.4	0.092	0.213	0.359	0.519	0.606	0.660	0.698	0.686	0.583	0.270	2.51					
2.4 – 2.6	0.087	0.202	0.353	0.527	0.620	0.681	0.746	0.757	0.715	0.597	0.267	2.71				
2.6 – 2.8	0.083	0.193	0.346	0.530	0.626	0.693	0.774	0.804	0.794	0.729	0.603	0.262	2.91			
2.8 – 3.0	0.081	0.188	0.337	0.528	0.626	0.697	0.787	0.831	0.840	0.808	0.736	0.599	0.258			
														3.11		
3.0 – 3.2	0.080	0.184	0.330	0.520	0.622	0.695	0.790	0.843	0.860	0.850	0.812	0.738	0.598	0.253	3.31	
3.2 – 3.4	0.078	0.181	0.322	0.508	0.616	0.690	0.786	0.844	0.869	0.870	0.855	0.814	0.734	0.593	0.249	3.56
3.4 – 3.6	0.077	0.178	0.316	0.496	0.608	0.681	0.778	0.841	0.871	0.880	0.876	0.854	0.807	0.726	0.580	0.056
3.6 – 3.8	0.076	0.176	0.311	0.486	0.597	0.670	0.771	0.836	0.870	0.886	0.888	0.876	0.852	0.802	0.720	0.448
3.8 – 4.0	0.075	0.174	0.307	0.478	0.584	0.658	0.762	0.828	0.866	0.886	0.893	0.888	0.876	0.846	0.796	0.646

Number of electrons (+ and −) set in motion per Mev interval per electron of material per photon per cm^2 per Mev interval

Multiply table values by 10^{-27}

using the γ-ray real absorption coefficient, μ_a, as

$$E_2 = \int_0^{h\nu_{max}} N(h\nu) h\nu \mu_a d(h\nu) \quad (3)$$

where $N(h\nu)d(h\nu)$ is the number of photons of energy $h\nu$ crossing unit area. These expressions E_1 and E_2 can be shown to be identical. Using Eq. 3, one does not consider in detail the energy distributions of the electrons set in motion since the absorption coefficient μ_a takes this into account.

When radiation losses are excluded from the energy locally absorbed one cannot use Eq. 2, nor can one use Eq. 3 since the γ-ray absorption coefficient includes all energy transferred to electrons even if subsequently re-radiated.

As the electron loses an increment of energy dE at energy E, the fraction locally absorbed is then $(S^{coll}/S^{total})\,dE$, where S^{coll} is the rate of loss of energy due to collisions. Hence the total energy locally absorbed as an electron of energy E_i comes to rest is

$$\int_0^{E_i} (S^{coll}/S^{total})\, dE$$

Since $N(E_i)$ is the number of electrons per cm^3 of energy E_i set in motion by the incident photons, the energy locally absorbed per unit volume is

$$E_{absorbed} = \int_0^{E_{i\,max}} N(E_i)\, dE_i \int_0^{E_i} \frac{S^{coll}}{S^{total}} dE \quad (4)$$

If radiation losses are important this will be quite different from Eq. 2.

The energy locally absorbed can also be obtained directly from the electron flux, $N(E)$. The energy abstracted per cm^3 from the electrons of energy E by collision processes is given by $N(E)S^{coll}\,dE$. Thus the total energy locally absorbed per cm^3 is

$$E_{absorbed} = \int_0^{E_{max}} N(E) S^{coll}\, dE \quad (5)$$

This equation appears to be very different from Eq. 4, but the two can be shown to be identical by substituting the expression for $N(E)$ given in Eq. 1. In general, Eq. 5 is easier to use than Eq. 4.

Ionization in a cavity. The energy locally absorbed in the gas of a cavity can be found by replacing S^{coll} in Eqs. 4 and 5 by the collisional stopping power of the gas. The cavity must be small enough that essentially all the electrons arise in the cavity walls, and hence $N(E_i)$ and $N(E)$ are determined by the walls.

If we divide the energy absorbed by W, the energy required to produce an ion pair, we obtain the ionization per unit volume

$$J = \frac{1}{W}\int_0^{E_{i\,max}} N(E_i)\,dE_i \int_0^{E_i} \frac{S_{gas}{}^{coll}}{S^{total}}\,dE \tag{6}$$

or

$$J = \frac{1}{W}\int_0^{E_{max}} N(E) S_{gas}{}^{coll}\,dE \tag{7}$$

In general, Eq. 7 would be easier to evaluate than 6.

Ion density distributions. In many biological investigations, one is interested in the ion density distribution of electron tracks. The mean ion density can be found by taking the ratio of the total number of ions produced per cm³ to total range of all the electrons.

The range of an electron of energy E_i is given by

$$R_i = \int_0^{E_i} \left(\frac{\Delta x}{\Delta E}\right)^{total} dE = \int_0^{E_i} \frac{1}{S^{total}}\,dE \tag{8}$$

The number of electrons with energy E_i to $E_i + dE_i$ produced per cm³ is $N(E_i)\,dE_i$ and the total of these electrons' ranges is $R_i N(E_i)\,dE_i$. To obtain the total path length of the electrons of all energies produced per cm³, we integrate as follows

$$R_{total} = \int_0^{E_{i\,max}} N(E_i)\,dE_i \int_0^{E_i} \frac{1}{S^{total}}\,dE \tag{9}$$

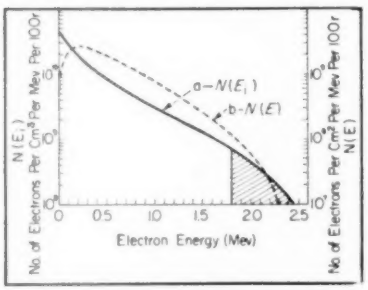

FIG. 3 Curve a: Energy spectrum of electrons produced in 1 cm³ of water by γ-rays of Fig. 2. Curve b: Corresponding spectrum of electrons passing through 1 cm²

FIG. 4 Development of theoretical expression for N(E)

TABLE 6a—E_γ = 0–30 Mev, Compton Electrons

Number of Compton electrons per Mev interval per electron of material per photon per cm² per Mev interval

Multiply table values by 10^{-26}

Photon energy interval (Mev)	Electron energy (Mev) 0.1	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10	12	14	16	18	20	22	25
	0.609	0.843															
0 – 1	78.1	13.1	7.67														
1 – 2	12.2	11.6	11.8	2.67													
2 – 3	4.21	4.13	4.30	6.67	3.62												
3 – 4	2.11	2.10	2.11	2.61	4.74	4.62											
4 – 5	1.28	1.26	1.27	1.40	1.93	3.70											
							5.62										
5 – 6	0.856	0.846	0.851	0.895	1.05	1.54	3.04	4.62									
6 – 7	0.612	0.606	0.605	0.628	0.690	0.843	1.30	2.58									
7 – 8	0.458	0.454	0.455	0.466	0.496	0.562	0.709	1.12	9.12								
8 – 10	0.338	0.335	0.339	0.347	0.374	0.426	0.527	0.703	2.87								
										12.1							
10 – 12	0.424	0.422	0.424	0.429	0.440	0.459	0.492	0.546	0.818	2.35	12.1						
12 – 14	0.304	0.303	0.304	0.305	0.310	0.319	0.333	0.355	0.439	0.682	1.99	15.1					
14 – 16	0.227	0.227	0.227	0.229	0.232	0.236	0.243	0.253	0.290	0.369	0.586	1.72	17.1				
16 – 18	0.176	0.176	0.177	0.178	0.179	0.182	0.186	0.191	0.210	0.245	0.319	0.515	1.52	19.1			
18 – 20	0.141	0.141	0.141	0.142	0.143	0.145	0.147	0.150	0.161	0.179	0.213	0.281	0.459	1.36	21.1		
20 – 22	0.116	0.116	0.116	0.116	0.117	0.118	0.119	0.121	0.128	0.139	0.157	0.189	0.252	0.414	1.24	23.1	
22 – 24	0.0962	0.0962	0.0962	0.0966	0.0971	0.0979	0.0989	0.100	0.104	0.111	0.122	0.139	0.170	0.227	0.379	1.13	25.6
24 – 26	0.0817	0.0817	0.0817	0.0819	0.0821	0.0826	0.0833	0.0847	0.0871	0.0915	0.0984	0.109	0.126	0.153	0.209	0.348	0.677
26 – 28	0.0700	0.0700	0.0700	0.0702	0.0704	0.0707	0.0712	0.0719	0.0739	0.0769	0.0815	0.0883	0.0985	0.114	0.141	0.193	0.507
28 – 30	0.0607	0.0607	0.0607	0.0607	0.0608	0.0612	0.0616	0.0620	0.0635	0.0657	0.0688	0.0734	0.0801	0.0894	0.105	0.131	0.223

TABLE 6b—E_γ = 0–30 Mev, Pair Electrons

Number of electrons (+ and –) per Mev interval per electron of material per photon per cm² per Mev interval

Multiply table values by 10^{-27}

Photon energy interval (Mev)	Electron energy (Mev) 0.1	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10	12	14	16	18	20	22	25
0 – 1	1.56	1.76															
1 – 2	1.07	8.11	2.51														
2 – 3	1.77	3.63	3.20	3.51													
3 – 4	1.65	3.86	4.48	3.22	4.51												
4 – 5	1.53	3.59	4.43	4.65	2.92												
							5.51										
5 – 6	1.38	3.25	4.19	4.68	4.44	2.67	6.51										
6 – 7	1.24	2.99	3.90	4.47	4.53	4.17	2.42	7.51									
7 – 8	1.09	2.74	3.63	4.25	4.34	4.32	3.90	2.22	9.51								
8 – 10	1.82	4.89	6.58	7.85	8.12	8.18	8.04	7.56	1.88								
										12.5							
10 – 12	1.47	4.24	5.80	7.07	7.42	7.53	7.51	7.50	6.77	1.62	13.5						
12 – 14	1.23	3.73	5.15	6.38	6.80	6.95	6.97	6.96	6.92	6.08	1.41	15.5					
14 – 16	1.06	3.33	4.63	5.79	6.24	6.42	6.47	6.47	6.47	6.39	5.51	1.28	17.5				
16 – 18	0.93	3.03	4.19	5.31	5.74	5.95	6.05	6.07	6.05	6.03	5.95	4.99	1.16	19.5			
18 – 20	0.84	2.79	3.82	4.89	5.33	5.57	5.67	5.69	5.66	5.66	5.68	5.52	4.60	1.07	21.5		
20 – 22	0.78	2.57	3.51	4.57	4.98	5.22	5.32	5.36	5.33	5.33	5.34	5.32	5.18	4.27	1.00	23.5	
22 – 24	0.69	2.36	3.25	4.27	4.68	4.90	5.02	5.06	5.07	5.05	5.05	5.02	5.03	4.86	4.01	0.92	
24 – 26	0.64	2.17	3.02	4.02	4.44	4.65	4.77	4.80	4.80	4.78	4.77	4.77	4.82	4.79	4.58	3.76	27.0
26 – 28	0.56	2.02	2.83	3.78	4.20	4.41	4.53	4.60	4.60	4.54	4.53	4.53	4.59	4.62	4.58	4.33	2.54
28 – 30	0.49	1.88	2.66	3.56	3.98	4.21	4.32	4.39	4.40	4.36	4.33	4.32	4.37	4.40	4.43	4.36	3.92

TABLE 7—Initial Distribution of Electron Energies, $N(E_i)$, Produced by γ-Ray Spectrum of Fig. 2

Number of electrons/cm³ of water/Mev interval/100r

Multiply table values by 10^9

Photon energy interval (Mev)	(Photons/cm² per Mev per 100r) x 10⁻¹⁰	Electron energy (Mev) 0.02	0.05	0.10	0.20	0.30	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.0	2.20	2.50
0 – 0.05																	
0.05 – 0.10	0.4	0.55															
0.10 – 0.15	1.8	0.86	0.94														
0.15 – 0.20	4.0	3.78	3.50														
0.20 – 0.30	7.3	8.59	6.51	6.36													
0.30 – 0.40	10.0	6.49	5.62	4.55	3.46												
0.40 – 0.50	11.3	4.57	4.23	3.63	3.37	1.97											
0.50 – 0.60	12.0	3.30	3.12	2.84	2.43	2.97	1.10										
0.60 – 0.70	12.4	2.38	2.28	2.13	1.89	1.84	2.73										
0.70 – 0.80	12.3	1.83	1.78	1.70	1.56	1.46	1.58	0.21									
0.80 – 0.90	11.5	1.33	1.31	1.26	1.17	1.11	1.11	2.07									
0.90 – 1.0	10.7	0.99	0.98	0.95	0.90	0.87	0.85	1.07									
1.0 – 1.2	9.5	1.32	1.30	1.28	1.23	1.20	1.17	1.26	2.16								
1.2 – 1.4	8.0	0.80	0.79	0.78	0.76	0.74	0.73	0.75	0.87	1.48							
1.4 – 1.6	6.6	0.49	0.48	0.48	0.48	0.48	0.47	0.47	0.50	0.62	1.02						
1.6 – 1.8	5.5	0.32	0.32	0.32	0.32	0.32	0.32	0.31	0.32	0.35	0.46	0.74					
1.8 – 2.0	4.5	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.26	0.34	0.53				
2.0 – 2.2	3.6	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.16	0.18	0.24	0.38			
2.2 – 2.4	2.8	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.13	0.18	0.26		
2.4 – 2.6	2.0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.07	0.09	0.12	0.17	
2.6 – 2.8	1.2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.07	0.04
2.8 – 3.0	0.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03
Total number		38.1	33.7	26.8	18.1	13.5	10.6	6.68	4.40	3.01	2.10	1.47	1.01	0.70	0.44	0.25	0.07

TABLE 8—Total Energy Loss by Electrons in Water*

Electron energy, E_i (kev)	S^{total} (Mev/cm)	$\left\|\frac{dI}{dE}\right\|$ (ion prs. per micron per Mev)	Electron energy, E_i (Mev)	S^{total} (Mev/cm) With δ correction (14)	S^{total} (Mev/cm) Without δ correction	$\left\|\frac{dI}{dE}\right\|$ (ion prs. per micron per Mev)
1	137.0		0.5	2.11	2.11	2.91
2	84.0	very	0.6	2.03	2.04	1.81
4	49.9	large	0.8	1.94	1.96	0.760
6	36.5		1.0	1.90	1.93	0.311
10	24.3	5,920	1.5	1.87	1.92	0.0674
15	17.7	2,820	2.0	1.88	1.95	0.152
20	14.1	1,700	3.0	1.92	2.02	0.168
30	10.3	806	4.0	1.96	2.09	0.149
40	8.26	480	5.0	2.00	2.15	0.130
50	7.00	314	6.0	2.03	2.21	0.113
60	6.12	224	8.0	2.10	2.31	0.0893
80	5.02	130	10.0	2.16	2.40	0.0733
100	4.35	85.4	15.0	2.29	2.60	0.0504
150	3.42	38.6	20.0	2.42	2.77	0.0383
200	2.92	21.9	30.0	2.66	3.08	0.0250
300	2.46	9.41				
400	2.23	4.98				
500	2.11	2.91				

* Collision loss from Bloch's formula, radiative from Heitler's (9). Mean excitation potential $I_m(Z)$ from fitting Livingston-Bethe expression to proton energy loss data (12), namely 71.7 ev for water (15).

TABLE 9—Calculation of Ion Density Distributions in Water Irradiated by γ-Ray Spectrum of Fig. 2

E_i (Mev)	$N(E_i)\Delta E_i$ (e/cm³ per 100r) x 10^{-8}	$\int_{E}^{E_{max}} N(E_i)\,dE_i$ x 10^{-8}	$\frac{1}{S^{total}}$ (cm/Mev)	E (Mev)	N(E) (e/cm²/Mev per 100r) x 10^{-8}	$\left\|dI/dE\right\|$ (ion prs. per micron per Mev)	N(I) (e/cm²/ion dens. int. per 100r) x 10^{-8}	I (ion prs. per micron)	N(I) x I (ion prs./cm³/ ion den. int. per 100r) x 10^{-12}
0 – 0.2	7.9	132.7	0	0	0	–	–	–	–
0.02 – 0.05	10.8	124.8	0.0709	0.02	11.6	1700	0.0068	43.3	0.29
0.05 – 0.1	15.0	114.0	0.143	0.05	18.4	314	0.0585	21.5	1.26
0.1 – 0.2	21.6	99.0	0.230	0.1	22.8	85.4	0.267	13.4	3.58
0.2 – 0.3	15.6	77.4	0.342	0.2	26.5	26.5	1.21	8.98	11.8
0.3 – 0.4	11.8	61.8	0.406	0.3	25.1	9.41	2.67	7.54	20.1
0.4 – 0.5	9.4	50.0	0.447	0.4	22.4	4.98	4.50	6.85	30.8
0.5 – 0.6	7.5	40.6	0.474	0.5	19.3	2.91	6.64	6.46	42.9
0.6 – 0.7	6.0	33.1	0.490	0.6	16.2	1.81	8.95	6.23	55.7
0.7 – 0.8	4.9	27.1	0.502	0.7	13.6	1.16	11.7	6.07	71.1
0.8 – 0.9	4.0	22.2	0.510	0.8	11.3	0.760	14.9	5.98	89.2
0.9 – 1.0	3.3	18.2	0.515	0.9	9.37	0.491	19.1	5.92	113.0
1.0 – 1.2	5.0	14.9	0.518	1.0	7.72	0.311	24.8	5.88	146.0
1.2 – 1.4	3.50	9.94	0.521	1.2	5.18	0.0872	59.5	5.84	348.0
1.4 – 1.6	2.46	6.44	0.522	1.4	3.36	0.0309	109.0	5.84	637.0
1.6 – 1.8	1.70	3.98	0.520	1.6	2.07	0.0927	22.3	5.86	131.0
1.8 – 2.0	1.12	2.28	0.516	1.8	1.18	0.129	9.15	5.88	53.8
2.0 – 2.2	0.70	1.16	0.513	2.0	0.595	0.152	3.92	5.91	23.2
2.2 – 2.4	0.34	0.46	0.510	2.2	0.23	0.165	1.40	5.94	8.3
2.4 – 2.6	0.12	0.12	0.506	2.4	0.06	0.170	0.35	5.98	2.1

This is identical with Eq. 4 if S^{coll} is replaced by 1. Since Eqs. 4 and 5 represent the same quantity, the total range is also obtained by replacing S^{coll} by 1 in Eq. 5, to yield

$$R_{total} = \int_0^{E_{max}} N(E)\,dE \qquad (10)$$

Thus the integral of the electron flux density gives the total range.

The total number of ion pairs produced in a cm³ is the energy absorbed, given by Eqs. 4 or 5, divided by W, the energy required to produce an ion pair. The mean ion density is thus

$$I_m = \left(\int^{E_{max}} W^{-1} N(E) S^{coll}\,dE\right) \Big/ \int_0^{E_{max}} N(E)\,dE \qquad (11)$$

For example the area under curve b, Fig. 3, is the total range of all the electrons produced in a cm³ and is 20.8×10^8 cm. The energy absorbed is 56.4×10^8 Mev/cm³/100 r from Eq. 4 or 5.

For this example, Eq. 2 should give nearly the same energy absorption since there is little radiation loss at this energy. Equation 2 gives an energy absorption of 56.6×10^8 Mev/cm³/100 r or 90.7 ergs/cm³/r, slightly lower than 93 ergs/cm³/r generally accepted for water.

The mean ion density can be obtained from Eq. 11 and is 8.3 ion pairs per micron.

For more detailed information concerning the ion density distribution, a knowledge of the distribution $N(E)$ is required. The number of electrons crossing an element of area in the material with energies between E and $E + dE$ is related to the number of electrons that produce ion densities I to $I + dI$ along their tracks through that area by the relation $N(I)\,dI = N(E)\,dE$. Thus $N(I) = N(E)(dE/dI)$.

The number of ion pairs per unit length, I, is related to the collision loss by $I = S^{coll}(E)/W$. Values of I and dI/dE were calculated from this formula and are given in Tables 8 and 9. There is considerable uncertainty concerning the value of W for water—for the present calculations the value of 32.5 ev per ion pair has been used.

As an illustration, the ion density distribution $N(I)$ can be obtained from the electron flux distribution $N(E)$ (curve b, Fig. 3), using the dI/dE values given in Table 8, and Eq. 7. Both $N(I)$ and $N(I)\,I$ obtained in this way have been plotted in Fig. 5. The method by which these were calculated is illustrated in the last three columns of Table 9. $N(I)\,I$ gives the number of ions produced per cm³ at each ion density and possibly has more physical significance than the plot of $N(I)$ against I.

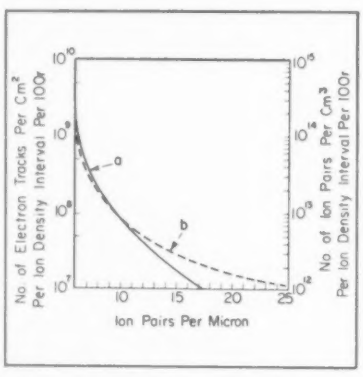

FIG. 5 Curve a: Distribution of electron track flux as a function of ion density along track. Original γ-ray distribution is that of Fig. 2. Curve b: Distribution of ionization per unit volume as a function of ion density along tracks

* * *

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On the Colorado Plateau:

Economics of Producing Uranium

What does it cost to find, to mine, to mill uranium? What return can be expected on the investment? Recently compiled figures for Colorado Plateau operations provide the answers to these questions.* Typical costs—for exploration programs, mining, transportation, and milling—and price structures are summarized here.

Annual operating budgets for exploration programs range from $345,000 to $1,000,000, with capital investments of $60,000–$220,000. Included are such items as exploratory drilling at $1–4 ft, airborne exploration at $3,000 per month for one plane (capital investment $6,000–12,000), and drill-hole logging to determine extent of ore at $900 per month per unit (capital investment of $5,000–10,000).

But a single prospector can carry on operations for much less. Without real hardship it takes about $3,000 for vehicle and equipment, about $2,500 a year for maintenance.

Mining costs per foot dug run $30–150, depending on type of shaft. Typical capital investment for a small mine is $25,000 (less than 100 tons/day).

Roads on which to haul ore from mine to mill cost $900–1,300 per mile. Haulage costs per ton-mile run 6–8 cents.

Milling capital investments are estimated at $10,000–15,000 per ton of capacity per day.

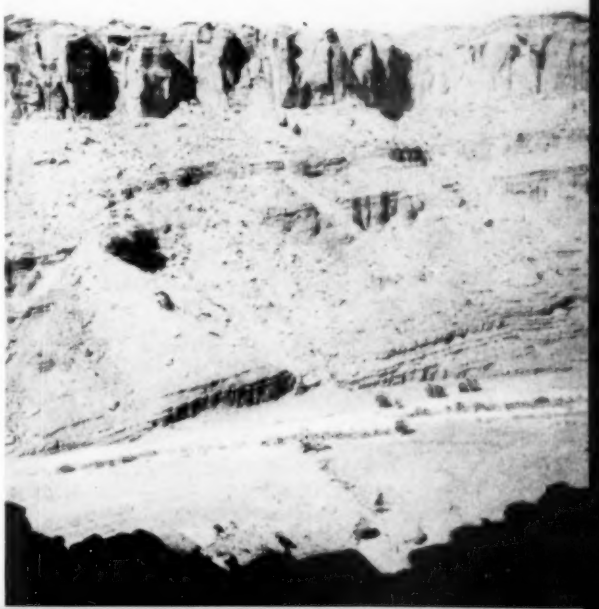
Prices paid by Atomic Energy Commission for uranium ore are specified in Circulars 5 and 6. Above 0.2% U_3O_8 per ton of ore, base price is $3.50/lb of U_3O_8. To this are added a grade premium ($0.75/lb for over 4 lb/ton, $0.25/lb for over 10 lb/ton), a mine development allowance of $0.50/lb, an initial production bonus of $3 to $700 per ton of ore for the first 10,000 lb, $0.31/lb for V_2O_5 in ore, and an allowance of 6 cents per ton-mile for up to 100 miles of haulage.

Excess haulage costs are sometimes paid by mill operators for high-grade ores on which they can make more money. AEC pays a fixed price for each pound of uranium concentrate produced, regardless of tons of ore processed.

Mill prices are set by AEC contract, usually for 5 years. Included is a "fair return," unofficially estimated at 10–15%.

* Data and photographs from *Engineering and Mining Journal*, a McGraw-Hill publication, which published a special report on uranium mining in its September, 1954, issue.

FRONT COVER and pictures here show four mining operations. Among them is largest ore producer on Colorado Plateau, but exact tonnages are not available. Anaconda's Jackpile mine (cover) in New Mexico is open-pit operation; entire overburden 100–120 ft deep is removed to get at 15–30 ft ore zone. Vanadium Corp. of America's Monument No. 2 mine in Arizona (top) has only 20-ft overburden. First tunneled, it is open pit now in effort to remove all ore. Steen's MiVida mine (above) in Utah is tunneled; picture shows operators loading ore. Across valley from mouth of Vernon Pick's Delta mine in Utah, ore-bearing strata lies at base of vertical rock formations (below)



Advances in ISOTOPE TECHNIQUES

New applications of radioisotopes to medical therapy and diagnosis, animal physiology and pathology, plant nutrition, biochemistry, chemistry, physics, and to industrial research and control were discussed by almost 800 delegates attending the Second Radioisotope Conference in England this year. Here is a comprehensive summary of the wealth of data presented there

By R. A. FAIRES, J. E. JOHNSTON, and ROSALEEN J. MILLETT
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THE WIDE RANGE of scientific, industrial, and medical subjects where radioisotopes are useful is indicated by a review of the Second Radioisotope Conference at Oxford, England, last July. The five-day meeting was sponsored by the Atomic Energy Research Establishment.

This article summarizes many of the papers presented. But space limitations prevented inclusion of all papers.

Industrial Applications

The photoneutron method of measuring deuterium provoked a lively discussion.

C. P. Haigh (Barrow Hospital, Bristol, England) used Na^{24} as a gamma-ray source with a BF_3 pulsed ionization chamber as detector. The predicted increase in sensitivity by using a ring of BF_3 proportional counters was estimated, and suggestions were made about replacing Na^{24} with an X-ray machine.

A. G. Maddock (Cambridge, England) pointed out that the sensitivity of the method could be increased by using a potassium permanganate solution as detector. Dr. Haigh's opinion was that the apparatus described would be more convenient for the routine assay of deuterium samples. With a 1-curie Na^{24} source, a 25-ml sample of 0.1% (by volume) D_2O can be measured to $\pm 2\%$ in about 860 sec, of which about 400 sec is for counting background.

A. H. Knight (Macaulay Institute for Soil Research, Aberdeen, Scotland) described a probe-type instrument capable of being lowered into a 1-in.-diameter bore hole to measure soil moisture. It measures the number of slow neutrons produced by collision of the fast neutrons from a radium-beryllium source with hydrogen nuclei in the soil. Indium and silver foils were used to measure the neutron flux. It was found that the hydrogen content of organic matter in the soil, and various salt concentrations did not affect the calibration of the instrument significantly. **J. Brochard** (Paris) gave comparative figures for a similar instrument that could use either (1) a sheet of indium between two cadmium foils as detector, thus using neutrons of well defined energy or (2) direct counting of neutrons with a BF_3 tube. **J. Sharpe** (London) suggested the possibility of using a lithium-iodide crystal and photomultiplier as a neutron detector.

Two new methods of measuring the low-level C^{14} activity required for dating archaeological specimens were described. As archaeological specimens are often small, it was considered an advantage in both methods to convert the samples into acetylene via CO_2 and lithium carbide. Acetylene, in addition to being a good counter gas, has two carbon atoms per molecule, thus increasing the specific activity of the counting gas.

A. R. Crathorn (Royal Institution, London) gave details of the proportional counter used for acetylene in the gas phase and the results obtained on archaeological specimens. It was claimed that dating back to 34,500 years could be achieved as compared with 22,000 years by Libby's method.

J. V. P. Long (Chemical Research Laboratory, Teddington, England) uses a scintillation method with acetylene dissolved at atmospheric pressure in a liquid phosphor (2:5 diphenyl oxazole in toluene containing 2% ethanol). At $-78°$ C the phosphor dissolved over 100 times its own volume of

acetylene. Direct comparison with samples measured in the acetylene proportional counter could thus be obtained. In preliminary results the background count is still considerably more than can be accounted for by analyzing it into its components.

E. N. Shaw (Aldermaston, England) described a gage for measuring thin tissues such as cigarette papers. Alpha particles from radium were used as the source, a windowless ionization chamber as detector. With a prototype instrument installed in a factory, stabilities of the order of $\pm 0.5\%$ were obtained over several hours; short-term variations of as much as 3% of the paper weight were experienced, probably due to temperature changes in the air gap.

J. L. Putman (Harwell, England) described a portable tube-wall thickness gage primarily designed for measuring the extent to which corrosion has occurred inside pipes in an oil refinery. A Co^{60} gamma-ray source is used with a scintillation counter consisting of a NaI crystal and an EMI type-6260 photomultiplier as detector. A gating circuit is used so that only the radiation that has undergone an energy change by scattering from the pipe is detected and not the direct Co^{60} radiations. Heavy lead shielding is thus avoided.

To study a textile problem **D. S. Taylor** (Wool Industries Research Assoc., Leeds, England) used P^{32} to label individual fibers. In drafting, (the attenuation of a rope-like assembly of fibers) it has been suspected that irregular movements of fibers have resulted in an uneven finished textile product. The time for individual fibers to move between two counters was measured, and hence the fiber path can be deduced. Autoradiographs were used to prove that the labelled fibers formed a natural part of the sliver. It was found that, contrary to the usual assumptions, the chance of a fiber being accelerated depended on the probability of its coming into contact with fibers gripped by the front rollers in the drafting process, and that the fiber when accelerated moves with a velocity intermediate between those of the back and front rollers.

A. Montens (Ruhrverband, Essen, Germany) has used Br^{82} both in solution and as small sources absorbed on sponge for the measurement of water flow in rivers and storage basins, and for determining the flow of sludge or sewage flow-through and hold-up time.

A. Quinton (Queen Elizabeth Hospital, Birmingham, England) reviewed the problem of dissipating electrostatic charges, particularly those encountered in operating theatres. He described an apparatus he had devised to blow ionized air towards the static charges, thus obtaining higher efficiency, and reducing the hazard from radiation that is present if a radioactive source is used near the apparatus producing the electrostatic charge.

H. S. Peiser (Sheffield, England) discussed the potentialities of Ce^{144} as a γ-ray source for industrial radiography. The use of a heterogenous source of gamma rays for radiography is advantageous for the inspection of specimens of widely different thicknesses as are often met with industrially. For the work described only a small source (56 mc) was available. The half-value layer for steel as determined by these studies was 1.5 ± 0.2 inches; this figure, however, increased with increasing steel thickness. Several people considered that this figure for the half-value layer was too high.

Chemistry

J. C. Bevington (U. of Birmingham, England) gave a large number of examples of the use of labelled reagents to study the mechanism of polymerization and the structure of polymers. He has studied branching of vinyl polymers, and described the use of tracer methods of analysis to determine the amounts of stable materials formed from the decomposition of initiators. As the quantities involved are often of the order of micrograms, this is a particularly valuable technique.

A. G. Maddock (University Chemical Laboratory, Cambridge, England) described an investigation of the exchange reaction between iodine and methyl iodide. He discussed the kinetics of the process, and was able to show that there was a chain mechanism initiated by radiation, and involving the production of free radicals.

E. J. Gibson (Fuel Research Station, Greenwich, England) described two uses of radioisotopes in chemical problems of fuel research. Using S^{35} it was shown that the contribution of SO_3 to sulphate formation on boiler tubes was almost independent of temperature, but that the formation from SO_2 increased rapidly above 600° C and was catalyzed by Fe_2O_3. Another study had been made to ascertain the role of oxygenated radicals in the Fischer-Tropsch process.

A. M. Gaudin (MIT, Cambridge, Mass.) described the use of a radioassay technique with C^{14}-labelled dodecylammonium acetate to measure the adsorption of the amine from aqueous solution. The adsorption is reversible; in the acid range it depends to a small extent on pH.

C. Bokhoven (Staatsmijnen in Limburg, Gelleen, Netherlands) described experiments in which $C^{14}O$ and $C^{14}O_2$ were passed over catalysts used in the synthesis of ammonia to study the poisoning of the catalyst. The activity of the catalyst and the activity of the outgoing gas were measured continuously. It was found that the poisoning in both cases agreed with the fact that if the CO or CO_2 is hydrogenated to methane, the water vapor formed poisons the catalyst. A supplementary experiment using water vapor as the poison was in agreement with this theory.

W. J. Arrol (Joseph Lucas, Ltd., Birmingham, England) described preparation of H^3 by the (n,α) reaction on Li^6 and subsequent purification, and also the preparation and purification of Kr^{85} from irradiated uranium. Industrial uses of H^3, e.g. in cold-cathode tubes, were emphasized. The main uses of Kr^{85} envisaged were again as a constituent of cold-cathode discharge tubes to insure that the time lag of break-down after applying a voltage is a minimum, in ventilation experiments as a tracer gas, and as a beta-particle source sealed in thin aluminium tubes for neutralizing static electricity.

Metallurgy

P. Albert (Centre d'Études de Chimie Metallurgique, Vitry-Seine, France) described a study of the purification of aluminium by zone melting, using Zn^{65} as a tracer, and measuring copper, sodium, and silicon by neutron-activation analysis. The best displacement velocity to obtain maximum purification was found. Purification resulting from repeated application of zone melting to the same ingot appeared to be in the ratio of a geometrical progression to the number of passages of the molten zone.

W. L. Mercer (U. of Leeds, England) has measured self-diffusion in alpha brass containing 1% and 27% zinc and in ordered beta brass. Precautions were taken to insure that the initial distribution of the tracer was planar. In

the discussion that followed, **U. S. Landergren** (Göteborg, Sweden) pointed out that the activation energy of 23.8 kilocalories/mole obtained by the tracer method for the self-diffusion of zinc into a 45% zinc brass is higher than the value of 19.3 kilocalories/mole obtained by chemical methods for the diffusion of zinc into a 47.3% zinc alloy.

Medical Therapy

R. C. Tudway (Bristol General Hospital, Bristol, England) described an applicator for the treatment of carcinoma of the cervix uteri using radioactive iridium. Since Ir^{192} emits less penetrating gamma rays than radium, the bladder and rectum can be more effectively shielded by using uranium and lead than was possible with one of the more orthodox methods. This method also permits greater flexibility in arranging a desired dose distribution.

F. Crainz (U. of Catania, Italy) described an applicator filled with Sr^{90}-Y^{90} for intrauterine beta-ray therapy of climacteric metrorrhagia. The very energetic beta particles of Y^{90} can penetrate to the deepest endometrial layers. The applicator is shaped so as to permit uniform irradiation of the whole surface of the uterine cavity. This technique permits complete destruction of the endometrium without impairing the ovarian function.

F. Ellis (Churchill Hospital, Oxford, England) described treatment of villous papillomatosis of the bladder using a colloidal solution of Au^{198} without a container, thus giving contact with the bladder wall.

E. E. Pochin (University College Hospital, London) discussed localization of colloidal radiogold in the lungs. The gold was precipitated onto sugar charcoal particles of 30–43 micron diameter that were suspended in dextran after irradiation. Experiments designed to show the proportion of the activity that remains in lungs or passes to the liver, with injection intravenously or through a cardiac catheter into a branch of the pulmonary artery, show little or no detectable escape to the liver. This makes possible intense local lung irradiation without liver damage from escaping gold particles. This preparation can also be localized in any specified area of the lung by means of cardiac catheterization. An interesting suggestion made in discussion was to use Y^{90} to replace Au^{198}.

J. T. Van der Werff (St. Canisius Ziekenhuis, Nijmegen, The Netherlands) used Bi^{206} in citrate form for interstitial therapy of radiosensitive tumors that cannot be treated satisfactorily by external X-ray irradiation or by radium implantation. The difficulty of localizing the Bi^{206} in the injection area for a reasonable time was overcome by adsorption on charcoal.

C. W. Gilbert (Christie Hospital, Manchester, England) showed that an exponential relationship existed between falling white cell count and accumulated dosage from P^{32} therapy. This enables a prediction to be made, at an early stage in treatment, of the minimum effective dose of P^{32} necessary.

Medical Diagnosis

H. G. Thode (McMaster University, Hamilton, Ontario, Canada) gave results of tests made on over 80 patients of the uptake of orally administered radioiodine in the salivary gland. Although saliva counts by themselves might be used as a rough radioiodine diagnostic test with fair confidence, the ratio of the counts in the saliva to those in the protein-bound iodine gives a more accurate test, particularly in the case of patients with questionable thyroid function, than the pickup and conversion tests that have been previously used. It was pointed out that the saliva activity takes into account both the secretion of radioiodine by the salivary glands and the secretion of radiothyroxin by the thyroid gland.

J. Rotblat (St. Bartholomew's Hospital, London) gave results on 93 patients, 12 in the carcinoma group, in support of a simple test to discriminate between carcinoma of the thyroid and euthyroid. This test is possible because, following intravenous injection of I^{131} in the carcinoma cases, the percentage of the blood iodide taken up by the thyroid per minute is lower and the biological half-life of radioiodine is shorter. These results could be explained by assuming that the increased rate of secretion of labelled hormone from the thyroid is due to a diminished store of iodine in the thyroid glands.

H. C. Allen, Jr. (Veterans Administration Hospital, Houston, Texas) described improvements in outlining brain tumors and regions of the thyroid gland that take up iodinated human serum and orally administered radioiodine respectively. The scintillation apparatus that discriminates in favor of 364-kev I^{131} gamma rays to improve resolution will be described in a forthcoming issue of NUCLEONICS.

W. Gemmell (Odstock Hospital, Salisbury, England) described an *in vitro* test of the viability of stored skin that involved taking a small piece of skin and placing it in a suitable Ringer solution containing P^{32}. Living skin shows an inverse exponential uptake of P^{32}, whereas dead skin does not actively incorporate P^{32}. Clinical experiments indicate that a negative P^{32} test is correlated with failure of the skin to "take" when grafted.

J. B. P. Williamson (U. of Cambridge, England) described how metallic transfer occurring in screwing and bolting operations in bone surgery has been studied by making the tool tips radioactive. Cr^{51} activity was used to measure metallic transfer. About 20–60 μg were transferred in screwing and 40–100 μg during bolting operations; the amount of transfer increased rapidly when slip occurred and was larger when the surfaces were of similar steel. Autoradiographs showed that the metal was transferred in the form of discrete particles. The medical interest of this work is that these particles may form electrolytic couples having a harmful effect on tissue healing.

Animal Physiology, Pathology

P. Lacroix (U. of Louvain, Belgium) used S^{35} and Ca^{45} combined with autoradiography to study bone metabolism at the histological level. He was able to show, by comparison of autoradiographs and microradiographs of the same section, that Ca^{45} accumulated where bone was growing, uptake being in inverse ratio to chromatism.

D. R. Maxwell (U. of Cambridge, England) described experiments on the uptake of tetra-sodium 2-methyl-3-Br^{82}-1:4 naphthohydroquinone diphosphate injected into the tail vein of rats with Walker carcinoma 256. The results are in qualitative agreement with the fluorescence method and confirm that the concentration of this bromine-labelled compound related to Synkavit (2-methyl-1:4- naphthohydroquinone diphosphate) is greater in tumor tissue than in other organs.

J. S. Robertson (U. S. Naval Radiological Defense Laboratory, San Francisco) described his results on the distribution and fate of Cr^{51}-labelled blood platelets injected into the exposed jugular veins of rats previously subjected to 500 r of 250-kv X-radia-

tion. The number of injected platelets remaining in the blood as determined by platelet counts was greater than that obtained by a radioactivity determination. The evidence is that some of the labelled platelets are injured and selectively removed and destroyed. Further work is needed before behavior of normal platelets can be studied.

Plant Nutrition, Allied Studies

R. Scott (Institute of Seaweed Research, Inveresk, Scotland) reported on the investigation of cesium accumulation by marine algae using Cs^{134}. The plant attempts to compensate for potassium deficiency by increased cesium absorption. No dependence of concentration factor on external cesium concentration was established, but a dependence of cesium accumulation on light intensity was indicated. Cesium is retained almost completely by the living algae, but when active plants were deliberately killed by immersion in boiling solvents, all the Cs^{134} was lost within a few hours. The distribution of cesium in *Rhodymenia palmata* plants was determined by autoradiography.

K. Kaindl (Osterreichischen Stickstoffwerke, Linz, Austria) discussed foliar fertilization with phosphatic nutrient labelled with P^{32} and showed that the uptake of KH_2PO_4 through the surface of the leaves depends on many parameters including temperature, humidity and soil, and on the developmental stage of the plant, the latter being most important. There are two periods in which the uptake is significantly high—the earliest developmental stage and just before the maximum vitality, which in the case of cereals is about one month after sowing.

Biochemistry

H. R. V. Arnstein (National Institute for Medical Research, London) has investigated the biosynthesis of benzylpenicillin from phenylacetylcysteine by adding (carboxy-C^{14})-diphenylacetyl-L-(S^{35}) cystine to fermentations and measuring both isotopes in the penicillin, phenylacetic acid and diphenylacetylcystine isolated at the end of the fermentation. It was concluded that phenylacetylcysteine is unlikely to be an intermediate in the biosynthesis of benzylpenicillin from phenylacetic acid and cysteine. α- and β-methylcystine are not utilized for the biosynthesis of 6- and 5-methyl-substituted penicillins respectively, which may indicate the specificity of the enzyme system concerned in the biosynthesis of the β-lactam ring of penicillin.

R. Michel (Collège de France, Paris) has investigated the speed and nature of certain excretory or degradation products after the injection of different amounts of labelled L-3:5:3′-tri-iodothyronine and L-thyroxine into thyroidectomized rats. The glucuronide of the hormone is excreted in the bile, and in the case of L-3:5:3′-tri-iodothyronine, is accompanied by the α-keto-acid derived from an oxidative deamination of the molecule. The same keto-acid is also present in the urine. The rate and quantity of these compounds eliminated in the bile varies according to whether the dose injected is physiological or pharmacological.

E. Kallee (Med. Klinik d. Univers., Tübingen, Germany) has detected trace proteins by a modified method of paper electrophoresis. He described application to detection of the proteohormone, insulin. After rats were injected intravenously with radioactive iodide and I^{131}-labelled serum and insulin, they were killed at various intervals and the radioactivity of different organs compared. It was possible, with the high radioactivity achieved, to make autoradiographs of the electrophoretic strips. As little as 0.001 μg of insulin could be detected in this way.

P. Schambye (Royal Veterinary and Agricultural College, Copenhagen) in his paper described some work on the *in vivo* conversion of C^{14}-glycerol into rat-liver glycogen. He found that there was asymetrical labelling of the glucose molecule of the glycogen. Carbons 1, 2, and 3 had higher specific activities than carbons 4, 5, and 6. It was found that the same result was obtained with chemically synthesized glycerol as with glycerol made by the degradation of glucose with leuconostoc mesenteroides.

Helen K. Porter (Imperial College of Science and Technology, London) has isolated hexoses from leaves previously exposed to high concentrations of $C^{14}O_2$ in bright sunlight. By means of biosynthesis, sucrose labelled in the fructose and glucose moieties was prepared. This was fed to disks of tobacco leaf, and the redistribution of C^{14} between the sugars, starch and carbon dioxide was followed. It was found that whether sucrose or invert sugar was used, and whether the glucose or fructose moiety was labelled, the specific activities of the starch and CO_2 were equal.

J. D. Hawkins (St. Bartholomew's Hospital, London) reported the use of I^{131}-labelled horse gamma globulin to investigate the fate of intravenously injected antigenic proteins in immune and normal rabbits. It was shown that in the case of immune rabbits, the protein is largely precipitated, disappears from the vascular system, and is deposited mainly in the liver, lungs and spleen within one hour. No similar behavior is observed with normal rabbits. Similar results were obtained with S^{35}-labelled protein antigen, and with the hapten, 3:5-diiodotyrosine.

* * *

Proceedings of the Second Radioisotope Conference, including all papers and discussion, will be published this fall by Butterworths, London. Volume 1 will cover medical, physiological applications; volume 2, physical sciences, industrial applications.

Transfer Studies

Three applications of radioisotopes to measuring exchange rates in the human body were presented:

D. S. Munro (*National Centre of Radiotherapy, Sheffield, England*) *studied exchange of radiosodium in the human body using Na^{22} and Na^{24}, with particular reference to the part played by the bone. The most reliable counting method was to use the counter in in vivo studies in contact with the skin over the patella.*

G. W. Reed (*General Infirmary, Leeds, England*) *studied aetiology and prevention of chemical imbalance, which is a late post-operative result of ureterocolic anastomosis. He showed by using Na^{24}, K^{42} and Cl^{38} that the migration of ions across bladder and intestinal epithelia is a dynamic process in which movement in both directions takes place. By means of these studies the optimum salt concentrations of perfusion fluids have been calculated to give minimum salt loss.*

P. Benda (*Institute Gustave Roussay, Paris*) *used radiosodium to study the sodium rate of exchange across the blood/cerebrospinal fluid barrier, both for investigating normal transfer processes in the barrier and for diagnosis. The technique was valuable in distinguishing tubercular and benign meningitis.*

Kinetics of Circulating Reactors at Low Power

Effect of delayed neutrons on the kinetic behavior of circulating-fuel reactors at low power is not predicted by simplified circulation-parameter theory. Instead, reactor periods can be calculated by finding eigenvalues of a system of differential equations

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KINETIC BEHAVIOR analysis of circulating-fuel reactors is complicated by the fact that delayed-neutron emitters are swept with the fuel into the heat exchanger, where some delayed neutrons are emitted and lost to the reactor system. The effect of the delayed-neutron loss on the circulating-reactor periods can be estimated crudely from the stationary reactor inhour equation, if effective values of the fission yields of the delayed-neutron emitters are used. However, an accurate description must involve the flow pattern and density variation of the delayed-neutron emitters. This article considers the kinetic behavior of a simple hydrodynamic model in which only the latter effect is important. Only low-power operation is considered—thus temperature effects are neglected.

Arbitrary Velocity

Only one group of delayed-neutron emitters is treated here, and it is assumed that prompt neutrons are governed by one-group diffusion theory. Extensions to more emitters and more energy groups are straightforward though cumbersome.

If the fuel circulates uniformly, the kinetic differential equations become*

$$\frac{\partial n}{\partial t} = \frac{M^2}{l_0}\nabla^2 n + \left[\frac{k(1-\bar{\beta})-1}{l_0}\right] n + \lambda c \quad (1)$$

$$\frac{\partial c}{\partial t} + q\frac{\partial c}{\partial z} = \bar{\beta}\frac{kn}{l_0} - \lambda c, \qquad 0 \le z \le a \quad (2)$$

$$\frac{\partial c}{\partial t} + q\frac{\partial c}{\partial z} = -\lambda c, \qquad a \le z \le a + l \quad (3)$$

where the core and heat exchanger have the same cross-sectional area. Equations 2 and 3 are the equations of continuity for emitters inside and outside the core.

When the core is a cube of side a, Eq. 1 becomes

$$\frac{\partial n}{\partial t} = \frac{M^2}{l_0}\left[-2\beta_0^2 + \frac{\partial^2}{\partial z^2}\right] n + \{[k(1-\bar{\beta})-1]/l_0\}\, n + \lambda c \quad (4)$$

if it is assumed that n depends on x and y through the factor $\sin \beta_0 x \sin \beta_0 y$ with $\beta_0 = \pi/a$.

Equations 2 and 4 have solutions of the form

$$n = Ne^{\alpha z + \omega t} \quad (5)$$

$$c = Ce^{\alpha z + \omega t} \quad (6)$$

where N and C are independent of z, providing that α and ω satisfy the equation

$$\alpha^3 + [(\omega+\lambda)/q]\alpha^2 + \left[\frac{k(1-\bar{\beta})-2M^2\beta_0^2-1}{M^2} - \frac{l_0\omega}{M^2}\right]\alpha + \left[\frac{k(1-\bar{\beta})-1-2M^2\beta_0^2}{M^2} - \frac{l_0\omega}{M^2}\right][(\omega+\lambda)/q] + (\lambda/q)(\bar{\beta}k/M^2) = 0 \quad (7)$$

This equation is obtained by substituting Eqs. 5 and 6 into Eqs. 4 and 2 and setting equal to zero the determinant of the resulting linear equations in N and C.

We require that n vanish at appropriate extrapolated boundaries

$$n(z=0) = n(z=a) = 0 \quad (8)$$

Although the condition is good enough for our purposes, it does not apply strictly, since the external medium is not a vacuum and can scatter neutrons back into the core. However, the medium is a strong absorber so that the thermal flux will diminish rapidly beyond the core boundary. If the fuel is composed of heavy elements, as it is, for example, in the Brookhaven U-Bi system,† the fast neutrons, both prompt and delayed, are unable to contribute to the thermal flux in this region or to cause appreciable fissions, since they lack a means of moderation.

A boundary condition for c can be obtained by requiring that it be continuous for each ω at the core inlet and outlet boundaries. Since Eq. 3 has a solution of the form $c = Ce^{\omega t - \omega z/q - \lambda z/q}$ this boundary condition is expressed by the relation

$$c(z=0) = c(z=a)e^{-\omega a/q - \lambda a/q} \quad (9)$$

Now Eq. 7, considered as an equation for α in terms of a given ω, has either one or three real roots. The latter possibility must be ruled out, for then the solutions in Eqs. 5 and 6 would

* A general exposition of one-group reactor kinetics is given by H. Soodak in "The Science and Engineering of Nuclear Power," Vol. 2, p. 89, C. Goodman, ed. (Addison-Wesley Press, Inc., Cambridge, Mass. 1949).

† C. Williams, F. T. Miles, NUCLEONICS **12**, No. 7, 11 (1954).

Symbols

a = core length
C = constant
c = delayed-neutron emitter density
l = length of heat-exchanger loop
l_0 = neutron lifetime $(\Sigma_a v)^{-1}$
k = infinite multiplication constant
k_0 = value of k that makes reactor just critical without circulation
L^2 = diffusion length
L_0^2 = value of L^2 for the critical stationary reactor
M^2 = migration area
N = constant
n = neutron density
P = probability that a neutron will be emitted in the core
$p(z)dz$ = probability that a delayed neutron is emitted at the point z in the core
q = circulation velocity
s = $(\omega + \lambda)/q$
t = time
v = neutron velocity
z = displacement along core axis
β = imaginary part of complex solution to Eq. 7
$\bar{\beta}$ = fission yield of delayed-neutrons emitters
β_0^2 = one-third critical buckling for stationary case
γ = real part of complex solution to Eq. 7
ϵ = increment in k
ϵ_0 = increment in k necessary to make reactor critical under circulation conditions
η = average number of fast fission neutrons emitted as a result of capture of one thermal neutron in the fuel
λ = emitter decay constant
ρ = reactivity
Σ_a = macroscopic absorption cross section
τ = neutron age
ω = reciprocal period

have to vanish identically to satisfy the boundary conditions. Hence we look for roots of α in the form $r_1 = \gamma + i\beta$, $r_2 = \gamma - i\beta$, $r_3 = \alpha_0$.

For a given ω, when sinusoidal form of the solutions is used, we obtain for n and c

$$n_\omega = [N_1 e^{\gamma z} \sin \beta z + N_2 e^{\gamma z} \cos \beta z + N_3 e^{\alpha_0 z}] e^{\omega t} \quad (10)$$

$$c_\omega = \frac{\bar{\beta}k}{l_0}\left[\left(\frac{(\omega+\lambda+q\gamma)N_1 + \beta q N_2}{(\omega+\lambda+q\gamma)^2+(\beta q)^2}\right) e^{\gamma z}\sin\beta z + \left(\frac{(\omega+\lambda+q\gamma)N_2 - \beta q N_1}{(\omega+\lambda+q\gamma)^2+(\beta q)^2}\right) e^{\gamma z}\cos\beta z + \frac{N_3 e^{\alpha_0 z}}{\omega+\lambda+\alpha_0 q}\right] e^{\omega t} \quad (11)$$

The coefficients in Eq. 11 follow from Eqs. 10 and 2.

Substitution of Eqs. 10 and 11 in the boundary conditions in Eqs. 8 and 9 yields three homogeneous linear equations in the constants N_1, N_2, and N_3. For nontrivial solutions, the determinant of this system must vanish. Expansion of the determinant yields the equation

$$[e^{\gamma a}\cos\beta a - e^{\alpha_0 a}]\left[\frac{\beta(1-e^{\gamma a - sl}\cos\beta a) + (s+\gamma)e^{\gamma a - sl}\sin\beta a}{(\gamma+s)^2+\beta^2}\right] + e^{\gamma a}\sin\beta a\left[\frac{(s+\gamma)(1-e^{\gamma a-sl}\cos\beta a) - e^{\gamma a - sl}\beta\sin\beta a}{(\gamma+s)^2+\beta^2} - \frac{(1-e^{\alpha_0 a - sl})}{\alpha_0 + s}\right] = 0 \quad (12)$$

Equations 12 and 7 define an infinite set of discrete eigen-values ω in terms of the reactor parameters, and in principle the reactor's kinetic behavior can be calculated for any set of initial conditions by employing the appropriate linear combination of the eigen-functions in Eqs. 10 and 11. For small reactivities, Eqs. 12 and 7 yield a single positive value of ω together with an infinite number of negative values. Of course, the negative components will decrease steadily with time, resulting in asymptotic expressions of the form of Eqs. 10 and 11 for the neutron and emitter densities. Since only a small proportion of the neutrons are delayed, circulation can cause but small deviation from the neutron density's usual sinusoidal shape. But the shape of the emitter density might undergo considerable distortion.

Infinite Velocity

As q approaches ∞, it is seen that

$$\lim_{q\to\infty}\alpha_0 = 0, \lim_{q\to\infty}\gamma = 0, \lim_{q\to\infty}\beta = \beta_\infty = \left[\frac{k(1-\bar{\beta}) - 2M^2\beta_0^2 - 1}{M^2} - \frac{l_0\omega}{M^2}\right]^{1/2} \quad (13)$$

Values of ϵ_0 in Units of $k_0\bar{\beta}$

q/a	$l/a = 0$	$l/a = 2$	$l/a = 4$
0.1	0.147	0.525	0.568
1	0.149	0.576	0.660
∞	0.149	0.576	0.661

Now, for large q, α_0 behaves as

$$\alpha_0 \approx -s - (\lambda\bar{\beta}k/qM^2\beta_\infty^2)$$

and

$$\lim_{q\to\infty}\frac{(1-e^{\alpha_0 a - sl})}{\alpha_0 + s} = \lim_{q\to\infty}\frac{(-\alpha_0 a + sl)}{\alpha_0 + s} = a - [(\omega+\lambda)(a+l)M^2\beta_\infty^2/\lambda k\bar{\beta}]$$

Hence, when the subscript on β is dropped, Eq. 12 takes the limiting form

$$4\sin^2(\beta a/2)/\beta = a + [(\omega+\lambda)/\lambda k\bar{\beta}](a+l)M^2\beta^2 \quad (14)$$

Equations 13 and 14 define an infinite set of eigen-values ω. For small reactivities, ω will have one positive and an infinite number of negative values. The limiting form of Eqs. 10 and 11 is

$$n_\omega = (N_1\sin\beta z + N_2\cos\beta z + N_3)e^{\omega t}$$
$$c_\omega = -(M^2\beta^2 N_3/l_0\lambda)\, e^{\omega t}$$

Circulation Parameters

The effect of circulation is frequently taken into account by using an effective value of $\bar{\beta}$ in the stationary reactor kinetic equations. This effective value is obtained by multiplying $\bar{\beta}$ by a circulation parameter P, which can be derived in the following way. Let $n(z)$ be the neutron density normalized to unity. Then

$$p(z)dz = \frac{dz}{1-e^{-\lambda(a+l)/q}}\int_0^z n(z')e^{-\lambda(z'-z)/q}dz' + \frac{e^{-\lambda(a+l)/q}dz}{1-e^{-\lambda(a+l)/q}}\int_z^a n(z')e^{-\lambda(z'-z)/q}dz'$$

is the probability that a neutron will be emitted in the core at the point z. The two integrals on the right side rep-

resent the contribution from emitters produced behind and in front of the point z, respectively. The factors in front of the integrals are the summations of series that sum the probabilities of emission after any of an infinite number of passes; P is then obtained by integrating $p(z)$ over the core length

$$P = \int_0^a p(z)dz \qquad (15)$$

If $n(z)$ has the form

$$n(z) = (2a/\pi) \sin (\pi z/a)$$

then

$$P = \frac{(\lambda a/\pi q)^2}{[1 + (\lambda a/q)^2]} + \frac{1}{2}\frac{[1 + e^{-\lambda l/q}]}{[1 - e^{-\lambda(a+l)/q}]}\frac{[1 - e^{-\lambda a/q}]}{[1 + (\lambda a/\pi q)^2]} \qquad (16)$$

If we assume that the effectiveness of the delayed neutrons varies with position, $p(z)$ in Eq. 15 must be multiplied by some weighting factor; if, for example, the weighting factor is sin $(\pi z/a)$, then

$$P = \frac{(\lambda a/\pi q)^2}{[1 + (\lambda a/\pi q)^2]} + \frac{2\frac{a}{\pi}\frac{\lambda}{q}[1 + e^{-\lambda a/q}][1 + e^{-\lambda l/q}]}{[1 + (\lambda a/\pi q)^2]^2[1 - e^{-\lambda(a+l)/q}]} \qquad (17)$$

The modified inhour equation can be obtained from Eqs. 2 and 4 by putting $q = 0$ and substituting $\bar{\beta}P$ for $\bar{\beta}$

$$\rho = l_0\omega + \frac{k\bar{\beta}P\omega}{\omega + \lambda} \qquad (18)$$

with $\rho = k - 3M^2\beta_0^2 - 1$. For $P = 1$, Eq. 18 is the standard inhour equation for a stationary reactor.

Numerical Results

Because of the complicated dependence of ω on the reactor parameters in the detailed theory, it does not appear feasible to express this quantity in terms of the reactivity $\rho = k_{eff} - 1$. It is convenient instead to calculate ω as a function of k.

It is necessary first to determine the value of k for which $\omega = 0$. This is done by setting

$$k = k_0 + \epsilon_0$$

where k_0 is defined as the value of the infinite multiplication constant that makes the reactor under consideration just critical without circulation. Then, if a value q of the circulation velocity is assumed, Eqs. 7 and 12 can be solved for ϵ_0 by iteration. When ϵ_0 is known, we put

$$k = k_0 + \epsilon_0 + \epsilon$$

and calculate ω as a function of ϵ again from Eqs. 7 and 12. Our model also requires us to introduce the explicit variation of M^2 with k. We assume this dependence to be of the form

$$M^2 = \tau + L^2 = \tau + L_0^2\left(\frac{\eta - k_0 + \epsilon_0 + \epsilon}{\eta - k_0}\right) = M_0^2\left[1 - \frac{L_0^2(\epsilon + \epsilon_0)}{(\tau + L_0^2)(\eta - k_0)}\right]$$

with

$$\frac{L_0^2}{(\tau + L_0^2)(\eta - k_0)} = 0.8$$

But whatever dependence of M^2 on k we assume, it should have no qualitative effect on the calculations' results.

The table lists values of ϵ_0, with $k_0 = 2$, $\bar{\beta} = 0.0076$, and $\lambda = 0.08$ (the reciprocal of the average mean life for the U^{235} emitters). Making use of

$$\frac{k_0 - 1}{M^2} = 3\left(\frac{\pi}{a}\right)^2$$

and formulae for solution of a cubic equation together with Eq. 7, we see that γ, β, and α_0 are proportional to $1/a$. Hence, from Eq. 12 it is evident that ω is independent of a, and the remaining relevant parameters are q/a (sec^{-1}) and l/a.

Curves of ω as a function of ϵ are given in Fig. 1 for $q = 0$ and for the cases in the table except for $q/a = 1$,

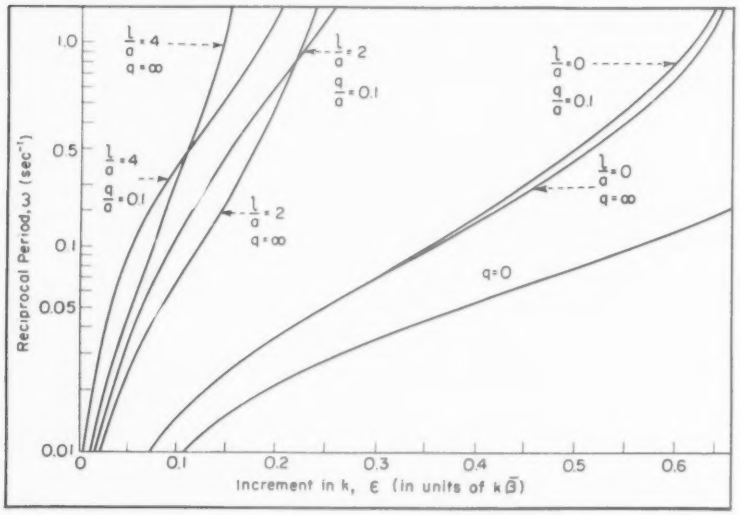

FIG. 1. Inhour curve (q = 0) and curves calculated from detailed theory

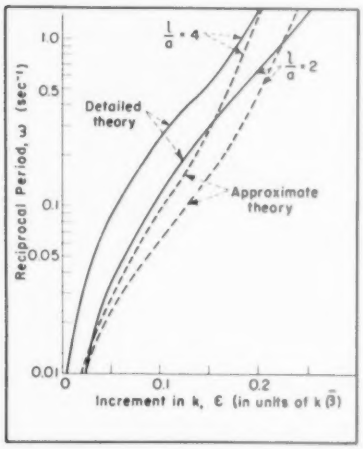

FIG. 2. Comparison of detailed and approximate theories when q a = 0.1

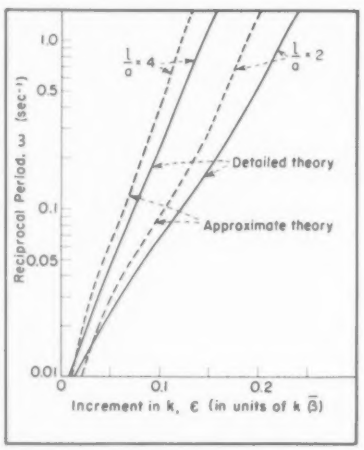

FIG. 3. Comparison of detailed and approximate theories when q a = ∞

in which case they are hardly distinguishable from the curves for infinite velocity. This means that for certain velocities of practical interest the infinite velocity approximation can be used with accuracy and considerable saving in labor.

The behavior of the curves for $q/a = 0.1$ is surprising because they show in places a steeper rise than the corresponding infinite velocity curves. Since the probability of delayed neutrons being emitted in the external loop is a maximum for infinite velocity, the minimum possible effect of delayed-neutron damping would be expected. The anomaly of Fig. 1 can be understood, however, if we assume that delayed neutrons have a different effectiveness according to where they are emitted in the core. For certain finite velocities most of the delayed-neutron emitters are bunched up well forward in the core—this results in low average effectiveness. On the other hand, the emitter distribution for infinite velocity is flat, so that it can sometimes make up in average effectiveness for what it lacks in amplitude. In fact, if ω did not depend on the shape of the emitter density, we would expect the $l/a = 0$ curves to coincide with the curve for $q = 0$. Obviously, as l/a becomes large, there must be a point at which the loss of delayed neutrons becomes so large that the infinite velocity case must be the one with the lowest damping. This tendency is indicated in Fig. 1. Also, curves for a sufficiently low velocity will lie entirely to the right of the infinite velocity curves.

Comparison

In Figs. 2 and 3 the results of the detailed theory are compared with results from the approximate Eqs. 16 and 18. As would be expected, the approximate curves exhibit no anomaly, since Eq. 16 is calculated without benefit of a weighting factor. This situation is not changed by weighting P with $\sin(\pi z/a)$ as in Eq. 17 or even with $\sin^2(\pi z/a)$. The values of P thus obtained might decrease faster with increasing q than for the unweighted case, but they do so monotonically. In fact, of the three forms, Eq. 16 seems in best agreement with the detailed theory for infinite velocity.

* * *

This work was sponsored by the U. S. Atomic Energy Commission.

The author expresses appreciation to Jack Chernick for illuminating discussions, and to Mrs. Edna Shelton for assistance in the numerical work.

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CROSS SECTIONS

Nomogram for Nuclear Reaction Calculations

By F. J. M. FARLEY
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Auckland, New Zealand

In the analysis of nuclear reactions, it is often necessary to relate the particle energy, direction, and intensity in the laboratory frame of reference to the corresponding quantities in the center-of-mass frame. This may be done rapidly with the nomogram provided.

The particle velocity in the center-of-mass frame is taken as known, and also the velocity of the center of mass itself; the ratio of these velocities is k. For a given laboratory angle ϕ, line 2 gives α. Equations 3 and 4 now determine the center-of-mass angle θ, and the angle β. Lines 5 and 6 then give the particle intensity $I(\phi)$ in the laboratory frame, assuming an isotropic distribution of particles (1 per unit solid angle) in the center-of-mass frame. Line 7 gives the ratio of particle energy in the laboratory frame to that in the center-of-mass frame.

If lines 6 or 7 come off the scale of I, it is permissible to divide or multiply the value of k' (obtained from line 5) by 10; this changes the answer by a factor of 100. Alternatively, in the case of line 7, one can use the points X or Y, instead of the point 90; the answer will then be multiplied correspondingly by 10 or by 50.

If the initial value of k is outside the range of the nomogram, Eq. 2 can be solved with a slide rule and the calculation completed on the chart.

Sample Calculations

As an example, the calculation for neutrons from the D + D reaction at 600-kev bombarding energy is set out below. The first step is to calculate the energy and velocity of the neutrons in the center-of-mass frame and the velocity of the center of mass. According to Mandeville (*1*), when a particle of mass M_1 and energy E_1 reacts with a stationary particle of mass M_2, giving rise to outgoing particles of masses M_3 and M_4 and energies E_3 and E_4, with energy release Q, then center-of-mass velocity $v_m = (2M_1E_1)^{1/2}/M$, where $M = M_1 + M_2$; energy of particle 3 in c. of m. frame $E_3 = (Q + E_1M_2/M) \times M_4/M = E_0$ in our notation; and velocity of particle 3 in c. of m. frame $v_0 = (2E_3/M_3)^{1/2}$. It follows that $k = v_m/v_0 = (M_1M_3E_1/M^2E_3)^{1/2}$.

Taking $Q = 3.28$ Mev (*2*), $M_1 = M_2 = 2$, $M_3 = 1$, $M_4 = 3$, and $E_1 = 0.6$, then for the emitted neutrons $E_0 = 2.68$ Mev with $k = 0.167$.

In this reaction the neutrons are not emitted isotropically in center-of-mass frame. At 600 kev the angular distribution (*3*) is given by $1 + 2.0 \cos^2 \theta$. The values of I given by the nomogram are to be multiplied by this function.

To calculate the intensity and energy at 0 deg and 180 deg, we use the simple rule

$$I = E/E_0 = (1 + k)^2 \text{ at 0 deg}$$
$$= (1 - k)^2 \text{ at 180 deg}$$

We can use the nomogram for this operation by setting $k' = (1 + k)$ or $(1 - k)$, $\beta = 90$ deg, and by following lines 6 and 7.

In the table, the value of k' is given for clarity, although there is no need to write it down in an actual calculation.

Further Example

As a further example, let us calculate the direction and energy of the Li^5 nuclei produced by Li^7 (d,p) Li^8 at a bombarding energy of 1 Mev. The Q value (*4*) is -0.2 Mev. In this case $E_0 = 0.064$ Mev, $k = 1.75$. Because k is greater than 1, the Li^8 nuclei go forward in a cone. The semiangle of the cone is found from the nomogram by setting $\alpha = 90$ deg and reading the value of ϕ (this is the maximum value

Sample Calculations Using Nomogram

Lab. angle ϕ *(deg)*	α *(deg)*	*C. of m. angle* $\theta = \phi + \alpha$ *(deg)*	$\beta = \frac{\pi}{2} - \alpha$	k'	I	$\frac{E}{E_0}$	E *(Mev)*	$(1 + 2\cos^2\theta)$	*Intensity*
				$D^2(d,n)He^3$ at 600 kev (neutron energy)					
0	0	0	90	1.17	1.37	1.37	3.67	3.00	4.11
30	4.7	35	85	1.15	1.32	1.33	3.56	2.35	3.10
60	8.2	68	82	1.06	1.13	1.13	3.03	1.28	1.44
90	9.3	99	81	0.99*	0.98	0.98	2.60	1.05	1.03
120	8.2	128	82	0.92*	0.85	0.84	2.25	1.76	1.50
150	4.7	155	85	0.85*	0.73	0.72	1.93	2.65	1.93
180	0	0	90	0.83*	0.69	0.69	1.85	3.00	2.07
				$Li^7(d,p)Li^8$ at 1 Mev (Li^8 energy)					
0	0	0	90	2.75	7.56	7.56	0.48	—	—
10	17.5	27.5	72	2.67	7.4	7.4	0.45	—	—
20	37	57	53	2.44	7.5	6.0	0.38	—	—
30	60	90	30	2.01	8.2	4.08	0.26	—	—
34	80	114	10	1.64	15	2.60	0.17	—	—

* Multiplied by 10 to keep answers on chart.

of ϕ permitted by the nomogram); $\phi_{max} = 35$ deg. Some energies and intensities calculated for this reaction, assuming isotropy in center-of-mass space, are included in the table. The intensity reaches a high peak as ϕ approaches 35 deg.

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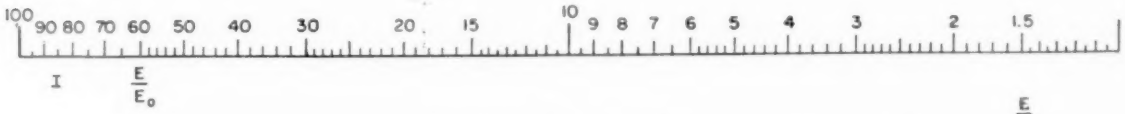
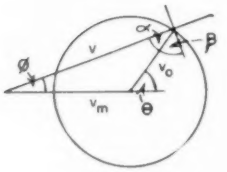




v_m = velocity of center of mass
v_0, E_0 = velocity, energy, in c. of m. frame
v, E = " " " lab "
θ = angle in c. of m. frame
ϕ = angle in lab frame
$I(\phi)$ = intensity in lab frame

Equations and procedure for utilizing nomogram

$$k = v_m / v_0 \quad \text{——— 1}$$

$$\sin\alpha = k \sin\phi \quad \text{——— 2}$$

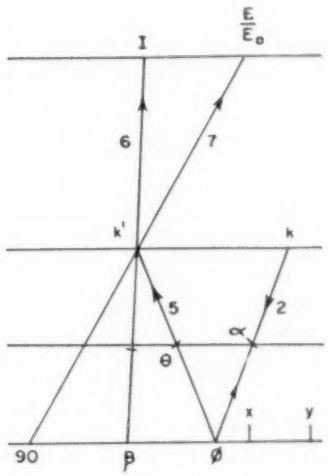
$$\theta = \phi + \alpha \quad \text{——— 3}$$

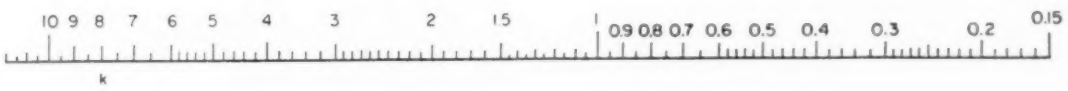
$$\beta = \pi/2 - \alpha \quad \text{——— 4}$$

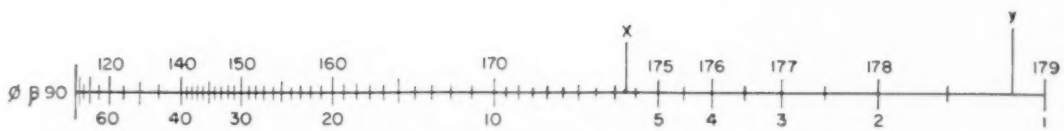
$$k' = \frac{v}{v_0} = \frac{\sin\theta}{\sin\phi} \quad \text{——— 5}$$

$$I(\phi) = \frac{\sin^2\theta}{\sin^2\phi} \times \frac{1}{\sin\beta} \quad \text{——— 6}$$

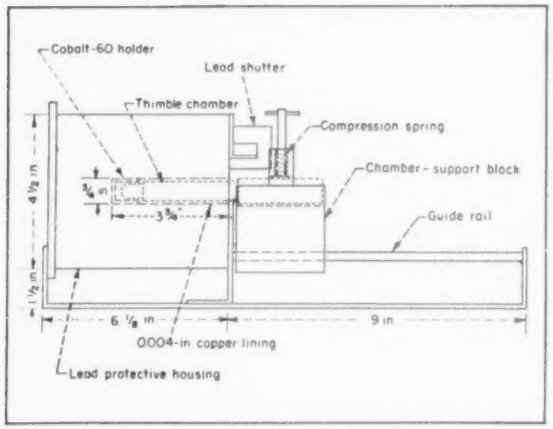
$$\frac{E}{E_0} = k'^2 \quad \text{——— 7}$$

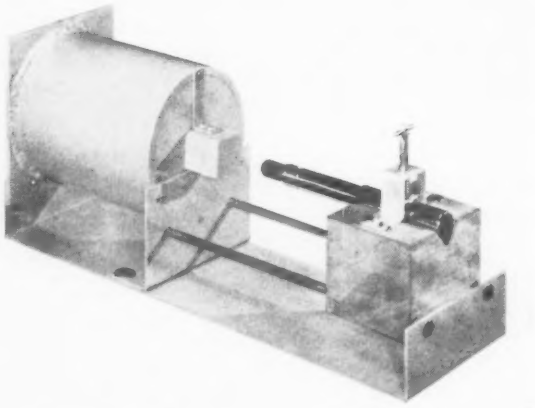






NUCLEAR REACTION NOMOGRAM for relating particle energy, direction, and intensity in laboratory frame of reference to corresponding quantities in center-of-mass frame. Graph at upper right indicates use of chart (if I or E/E_0 comes off scale, multiply k' by 10 or 0.1)





SHIELD is steel pipe filled with lead and welded to steel plate at one end. Piece of lead 1⅛ in. square and 1¾ in. thick is mounted as pendulum shutter. Block holding chamber rides on ¼-in. steel rods; V-cut in block and plate on front of block position chamber. Chamber is held by compression spring. Source holder is secured by two screws inserted into lead shield

Cobalt-60 Unit for Checking Thimble Chambers

By E. DALE TROUT, JOHN P. KELLEY and ARTHUR C. LUCAS
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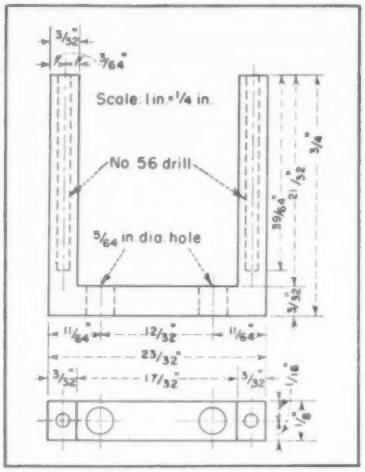
General Electric Company
Milwaukee, Wisconsin

A simple unit utilizing 14 mc of cobalt-60 was constructed for periodically checking thimble chambers used with a Victoreen r-meter.

The source consists of two pieces of Co^{60} wire, each approximately 1 cm long and 1 mm in diameter. Before activation, the wire was gold plated to reduce scaling after irradiation.

For the past two years, the unit has been used for checking some 30 chambers. Typical chamber readings are: 11.6 r for 5-min exposure of 25-r Bakelite chamber, 61.0 r for 20-min exposure of 100-r Bakelite chamber, 177 r for 60-min exposure of 250-r Bakelite chamber, and 180 r for 60-min exposure of 250-r Nylon chamber. To reduce the effect of chamber material, i.e., Nylon or Bakelite, copper was used for the source holder and to line the exposure cavity.

Stray radiation is less than 6.25 mr/hr at 20 in. from the source.



SOURCE HOLDER is U-shaped piece of copper; holes in holder are pinched closed after inserting cobalt wire

Nuclear Emulsion Instability

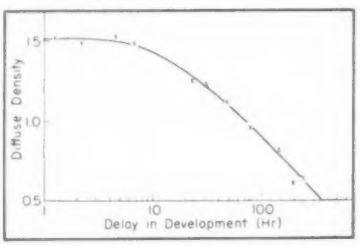
By J. S. CHEKA
Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Because of their low photon sensitivity, nuclear films have been considered as a supplement to X-ray type films to increase the dose range of a film dosimeter. A high-range dosimeter would be useful in case of accidental high exposure.

A troublesome characteristic of nuclear emulsions is the latent image instability. Gallimore* noted that fog due to gamma radiation faded faster than particle tracks when such emulsion was exposed to mixed γ and neutron radiations, and he delayed development to suppress gamma fog. Special consideration must be given to this latent-image instability in the use of nuclear emulsion for gamma measurement.

A series of NTA films were exposed to 100 r of Ra γ-radiation, then developed after various periods of delay. The resulting diffuse densities as measured on an Ansco densitometer appear in the graph. If the time of exposure is known, as it would be in case of a major accident, the instability of the latent image would not be a drawback.

Earlier tests† have shown a wide range of γ-response in several batches of nuclear emulsion, so that calibration of each batch is essential.



FADING of γ-produced density in NTA emulsion

* John Gallimore, personal communication.

† F. Western, J. S. Cheka, unpublished (1945).

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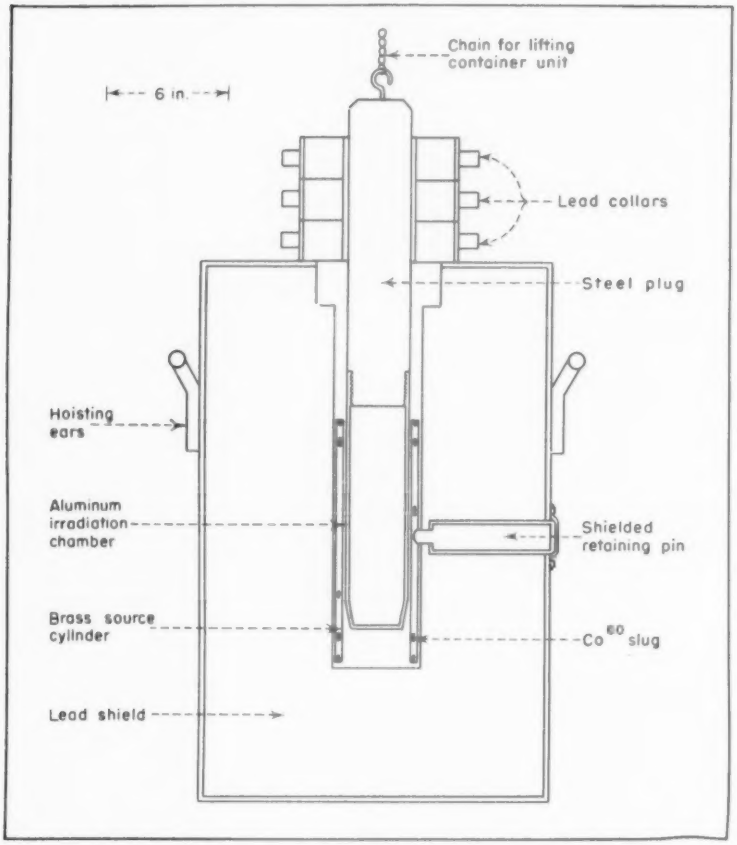

FIG. 1. Cross section of insect sterilization facility showing sample container raised about 2 in. above exposure position

A Gamma-Ray Source for Sterilizing Insects

By E. B. DARDEN, Jr., E. MAEYENS,* and R. C. BUSHLAND†
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A cobalt-60 irradiation unit was constructed for sterilizing screwworm fly (*Callitroga hominivorax*) pupae and as a research instrument for irradiating other insects and insect-infested materials. Since a source of this type needs to be calibrated at rare intervals, it is particularly useful where much routine work requiring good dosimetry is performed.

The source successfully meets the requirements of maximum irradiation chamber size and amount of Co^{60} within limits of portability and reasonable cost without violating accepted radiation safety standards, delivering about 12,000 r/hr/liter of material.

The unit weighs less than 2,500 lb, can be transported by truck or dolly, and, at current prices, can probably be constructed for less than $4,500. It was made at ORNL and installed at the Orlando Florida Laboratory of the Entomology Research Branch.

Control by Sterilization

Techniques for utilizing radiation in large-scale control measures are still largely experimental (*1*). One project that shows considerable promise is being carried out by the Entomology Research Branch of the U. S. Department of Agriculture against a livestock pest, the screwworm fly. The losses caused by screwworms amount to millions of dollars annually in the southwestern and southeastern States. In the southeast in average years, screwworms survive the winter only in Florida. The USDA is conducting tests to determine whether such an isolated population of screwworm flies can be eradicated through release of large numbers of infertile insects.

Under cage conditions, male screwworm flies mate repeatedly if virgin females are available, but female flies mate only once. Bushland and Hopkins (*2*) performed laboratory experiments that showed that irradiation of pupae with 5,000 r of X-rays causes sterility in adults but does not materially affect their mating habits. If a normal female were mated with a sterilized male, she would lay only infertile eggs. In cage tests with mixed populations of sterilized and normal insects, the ratio of infertile to fertile egg masses produced by normal females was proportional to the sterile/normal ratio in the male population. Bushland and Hopkins (*3*) also found that X-rays and Co^{60} γ-rays produce similar effects.

USDA small-scale field tests in Florida lent support to the laboratory findings (*4*). When sterilized male screwworm flies were released on Sanibel Island at the rate of 100 per square mile per week, the majority of the egg masses laid by "wild" females on wounded goats failed to hatch, while egg masses similarly collected in a control area were almost 100% fertile. The natural population of flies on Sanibel Island declined rapidly, as indicated by a great reduction in numbers of egg masses deposited. The island was not sufficiently isolated to prevent immigration of normal, fertilized females from adjacent untreated areas, so it is not known whether eradication could have been attained had the factor of migration been eliminated. The apparent success of those field tests justified experiments on a larger scale to obtain more conclusive data on the possibility of eradicating isolated populations of screwworms by outnumbering the natural male population through a continuous release of sterilized insects

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over a period of several generations.

For the field work summarized, the flies were sterilized with either X-rays or γ-rays from an 11-curie distributed-type Co^{60} source supplied by the ORNL Biology Division. X-ray sources, though suitable for laboratory studies and small-scale releases of insects, are quite expensive for the mass production of the millions of sterile individuals required for large-scale releases. The success attained with the small source indicated that a similar device with a suitably larger capacity and a few minor modifications to increase the convenience of handling would be satisfactory and probably not too expensive for the expanded work.

Entomological Requirements

Screwworm pupae are easily handled and, for sterilization, can be poured into a suitable container much as one would handle grains of wheat, although the pupae are larger (9–10 cm^3 per 100 insects). The pupae have a density about equal to that of water.

It has been a common practice to rear as many as 100,000 per week, but field experiments may require as many as 1,000,000 sterilized insects each week. The combination of source capacity and dose rate should be such that one man working full time could sterilize (with 5,000 r) 1,000,000 insects in a 40-hr week, or 25,000/hr. Since the source was also to be used as a research instrument, it was to be of sufficient flexibility to permit irradiation of other insects or insect-infested materials.

Source Description

To obtain the desired sterilization rate, the initial strength of the source was to be such as to permit at least two sterilizing doses to be delivered in an hour to approximately 800 or 900 cm^3 of pupae per dose. It was estimated that about 70 curies of Co^{60} would provide the necessary dose rate and provide for uniform intensity over the irradiated volume.

The major component is a lead-filled cylindrical steel shell with a central well 19 in. deep containing the source. This also serves as the shipping container (see Fig. 1). Around the opening to the well is a collar 6 in. high, composed of three doughnut-shaped pieces of lead also incased in steel, stacked one upon the other. The doughnuts are equipped with aligning pins. Each can be suspended by a sling from an overhead pulley and, when the shield is installed in its permanent position, maneuvered into place by a long handle with a threaded end that screws into one side of the doughnut. The collar need not be removed unless the facility is to be transported, at which time a large lead plug is inserted that seals off the well flush with the top.

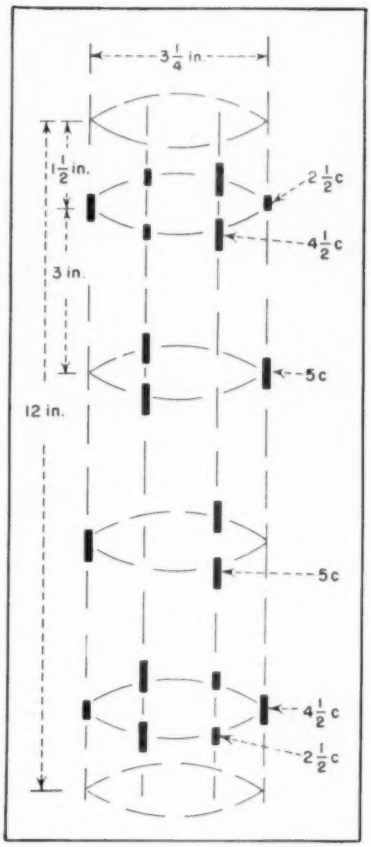

FIG. 2. Lattice arrangement of Co^{60} slugs in γ-ray source

Fitting closely down inside the well is a 3½-in.-outside-diameter open brass cylinder, 12 in. long, with walls ¼ in. thick containing the Co^{60}. The latter is in the form of ⅛-in.-diameter slugs distributed in a hexagonal lattice and held in long holes drilled parallel to the axis of the cylinder on six centers uniformly spaced about the periphery (Fig. 2). Small drain holes connecting the holes for the slugs with the outside of the cylinder are provided to permit the escape of moisture in case the cylinder is to be loaded under water. The activity is distributed symmetrically with respect to the center of the cylinder with a somewhat higher concentration terminally to minimize as much as possible the natural attenuation of the radiation field near the ends. A total of 18 slugs are used, the longitudinal spacing being established by the depth of the hole and by inserting metal spacers. On a given center, one ½-in.-long slug of approximately 5 curies is located with its center 4½ in. from the end of the brass cylinder, one ¼-in. slug of 4½ curies, 1½ in. from the opposite end. The order is reversed on alternate centers.

The container in which the insects are irradiated is a heavy-walled aluminum cylinder with the following dimensions: length, 14 in.; walls, ¼ in. thick; inside diameter, 2½ in.; volume, 900 cm^3. The outside is slightly tapered on the lower end to facilitate its insertion into the source. It is essential that the container should fit loosely into the radiation source. About 1/32-in. clearance is provided. A threaded steel plug serves both as a top for the container and as a radiation shield when the container is down in the source. A light chain and overhead pulley arrangement provided for manipulating the assembled container and plug enables one man to carry out the irradiation procedure.

The distribution of radiation intensity in the source approximates that in a thin, uniformly radioactive cylinder (*5*). The dose received by biological material irradiated in the aluminum container was calibrated with a thimble-type ion chamber (*6*) in the following manner: The aluminum cylinder filled with a polystyrene phantom was lowered into the exposure position. Ionization measurements, with the chamber thrust into the polystyrene insert, were then made along the axis of the cylinder. Polystyrene closely approximates "wet tissue" in its electronic density and stopping power (*5*). The dosimeter consists of a chamber with a 2-cm^3 cavity volume constructed essentially of polystyrene attached to a probe of the same material. With the irradiation cavity buried, as it were, in a polystyrene phantom, the radiation energy absorbed in the immediate vicinity was determined directly by applying the Bragg-Gray principle.

A relative exploration of the field inside a Lucite phantom filling the space inside the aluminum insert was made with a Victoreen r-meter. The phan-

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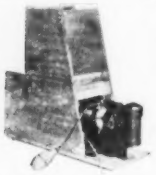

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tom was composed of two Lucite cylinders, one fitting eccentrically inside the other. The Victoreen chamber was fitted into a cavity, also off center, in the inner cylinder so that by rotating it inside the other cylinder the axis of the dosimeter could be displaced as much as $\frac{5}{8}$ in. from the source axis. In this way the field inside the region thus mapped out over a range of depth of 9 in. ($4\frac{1}{2}$ in. above and below the center of the source) was demonstrated to possess no variations in intensity greater than $\pm 13\%$ of the mean, while the variation along the axis only was reduced to $\pm 6\%$. We regard this nonuniformity as surprisingly low in view of the economy and simplicity of design of the source.

Safety Considerations

In use, the facility is housed in a concrete shed separate from the main entomological laboratory buildings. A concrete base elevates the shield 16 in. above the floor so that the opening in the top is about shoulder high. It is not necessary for the operator to be closer than 5 ft to carry out normal operational procedures. The lead doughnuts around the top opening are essential for safe operation. With these in place and with the plug removed, the radiation level in the working space up to within about 3 ft of the shield was below the accepted tolerance value (10 mr/hr) for an 8-hr working day.

To add an additional safety factor, lead bricks were stacked up around the collars to a height of 8 in. and permanently strapped into place. By this procedure, the radiation level in the room during loading and unloading procedures was rendered essentially negligible except for the region directly over the shield. A small component found to be leaking through around the three retaining pins in the side of the shield was reduced to insignificance by capping the head of each pin with a lead brick.

* * *

The work at Oak Ridge was performed under Contract W-7405-eng-26 for the U. S. Atomic Energy Commission. We wish to acknowledge the assistance of Dr. C. W. Sheppard in establishing the specifications of the source.

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Simple Efficient Shield for Well-Type Scintillation Crystals

By JOHN W. IRVINE, Jr.

Department of Chemistry and Laboratory for Nuclear Science
Massachusetts Institute of Technology, Cambridge, Massachusetts

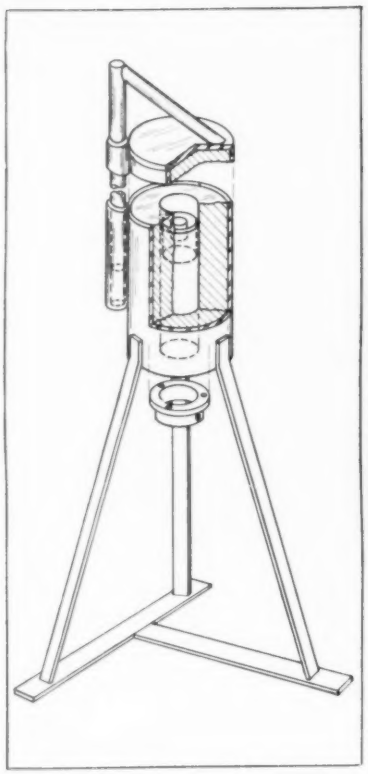
Well-type NaI(Tl) crystals* for scintillation counters are ideally suited for routine analytical use in tracer experiments involving gamma-ray or high energy beta-ray emitters. Counting samples are usually solutions and necessitate mounting the crystal in an upright position. The shield described here was designed to reduce the background in such a crystal.

The body of the shield is a 10-in. length of 7-in. o.d. steel tube to which a tripod has been welded. On one side, a length of 1-in. i.d. heavy-wall steel tube is welded. Several small studs are welded on the inside of the case and a lead cylinder with a $2\frac{1}{2}$-in. bore and approximately 2-in. walls cast in the case.

The cap for the shield consists of a steel shell as shown with a 2-in.-thick lead plate cast in.

A 1-in. steel rod welded to the side of the cap rotates in the tube on the side of the body. The end of the bearing tube is cut on a slight angle to provide an inclined plane for a portion of the sleeve brazed on the rod. In this way, as the cap is rotated around the axis of the hinge, it is lifted approximately $\frac{3}{32}$ in., providing adequate clearance for free rotation.

* Harshaw Chemical Co. (Cleveland, Ohio), type No. 22.



SHIELD for well-type counter

The counting head, consisting of crystal, photomultiplier, socket, resistors, etc., is mounted in a brass tube that fits loosely in the center hole of the shield. This assembly is held in place and positioned vertically by a set screw in a brass ring fastened to the bottom of the shield.

A shield of this design uses less lead than a brick "castle," provides secure mounting of the crystal-photomultiplier assembly, and makes easy access to the sample position possible without lifting the weight of the top.

Shielding the NaI(Tl) crystals has a much more pronounced effect on the background than similar shielding on a G-M counter. Because of the very high efficiency for detecting relatively soft electromagnetic radiation, natural radioactivity in materials of construction makes a much larger contribution than cosmic radiation to the background. Thus 2 in. of lead reduce the background of a typical end-window G-M counter to one-third the unshielded value, but the same amount of lead reduces background of a standard well-type crystal to $\frac{1}{10}$ the unshielded value.

* * *

This work was supported in part by the U. S. Atomic Energy Commission.

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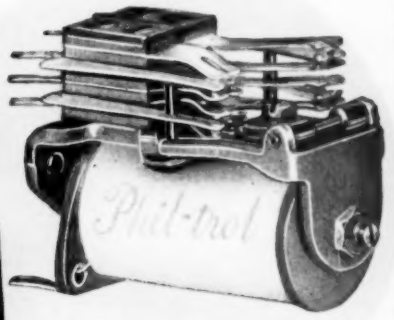

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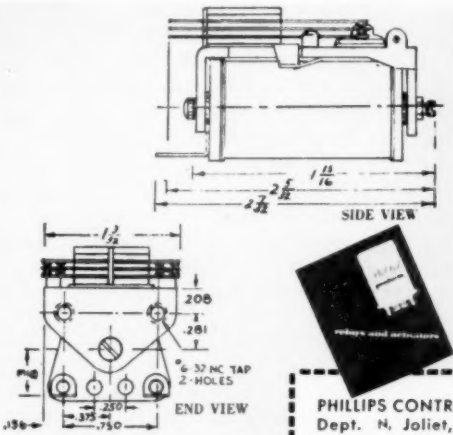

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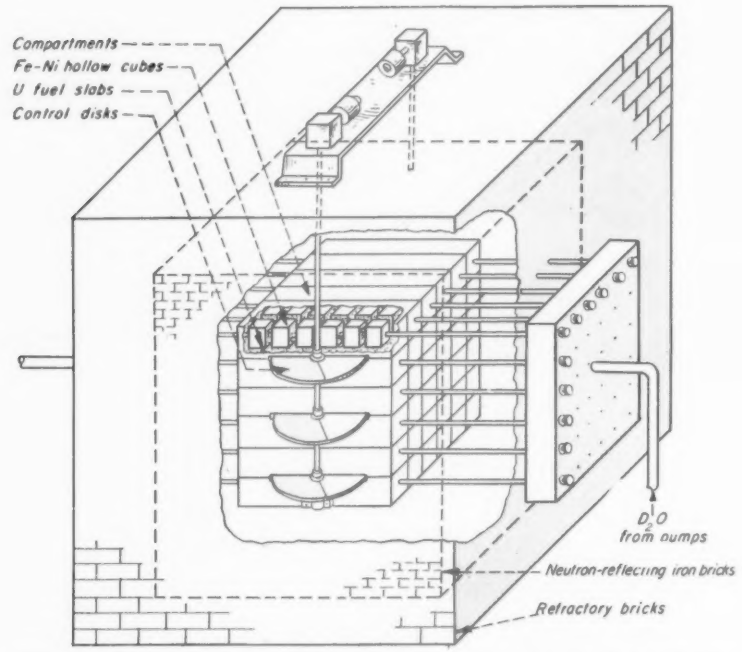

TYPICAL REACTOR DESIGN described in Swiss patent 233011 indicates that devices for using nuclear energy were being conceived in 1939

Is This the First Reactor Design?

As early as May 1, 1939, just five months after the announcement of the discovery of fission, a reasonable idea for a nuclear power reactor was set forth in writing as a step toward a patent application. Included in the application are descriptions of the functions, importance, and relationships of fuel, moderator, coolant, and control elements. Illustration above shows reactor cited as an example of the principles stated in the application.

The patent is another indication that the United States has had no monopoly of ideas in the field of reactors, even during the infancy of atomic energy work (for similar indications, see NU, Sept. '53, p. 76).

The National Center for Scientific Research, Paris, France, applied for the Swiss patent on April 19, 1940; it was granted June 30, 1944, with a priority to May 1, 1939.

The inventors found that a light substance arranged near the fissioning uranium would slow the emitted fast neutrons so that they would cause more fissions in a chain-reacting process. After reviewing possible fates of the liberated neutrons, the patent states that, by proper arrangement of moderator, fuel, reflector, and absorbers, a continuous energy-liberating chain reaction can be established that will not result in explosive dismemberment (it might be assumed that this also implies that an explosive process can be formed). Thus, a stabilized reaction furnishes usable energy from transmutation of the fuel. An example of such an energy-transforming device illustrates a practical application of the process.

As shown in the figure, the proposed reactor consists of 36 long compartments, each containing six 5.9-in. cubic iron-nickel boxes. Spaces between cubes and compartments are occupied by uranium slabs. An inert gas (CO_2) circulates in the fuel chamber to prevent oxidation of the uranium.

Heavy-water moderator (99.6% pure) acts as coolant by being circulated through the boxes to heat exchangers, from which it is pumped back to the core. High-pressure normal water picks up heat in the exchangers and transfers the energy to turbines.

The compartments are contained in a 43-in. cubic iron box that is surrounded by a neutron reflector consisting of iron bricks stacked to a thickness of about 18 in. Refractory bricks stacked beyond the reflector serve as thermal insulation. The entire assembly is surrounded by a radiation shield (not shown on figure).

A Ra-Be neutron source located in the core's center aids in starting the reactor. Control mechanisms consist of electric-motor-rotated rods on which are mounted sheet-metal disks. Sectors of the disks are covered with neutron-absorbing cadmium. Rotation of rods causes varying amounts of cadmium to be inserted between the core compartment walls—thus controlling the power level.

A safety feature based on a negative temperature coefficient of reactivity can be introduced. The concentrations and distributions of the core's constituents can be such that changes caused by heating above a certain stabilization temperature stop the reaction. Because of this, and the fact that neutron leakage and cadmium's neutron absorption increase with temperature, the reaction can be controlled safely. If, at a certain moment, the energy produced exceeds that carried away, core temperature rises and slows the fission reaction; the core cools until the stabilization temperature is reached, the reaction accelerates again, and the cycle repeats.

About 300 Mw of heat is removed from the reactor when it is fueled by 11.75 tons of uranium and cooled by 190 gal of 1,320-lb/in² D_2O circulating at 3,180 gal/min with a maximum temperature of 610° F and 68° F minimum.

The patent application also describes alternate materials and configurations.

Either uranium or thorium, or a mixture of the two (as solid, liquid, gas, or compound) can be used as fuel.

Hydrogen, helium, beryllium, carbon, oxygen, paraffin, ordinary water, or heavy water (or other deuterium compounds) are suggested as possible moderators. Heavy water distributed in small volumes within the uranium mass is suggested as the best moderating arrangement. When used as a gas or vapor, the moderator's pressure can be varied as a means of reactor control. The reflector can be made of lead, beryllium, or calcium carbonate.

Control can be accomplished by cadmium or other neutron absorbers arranged either homogeneously or heterogeneously. These can be inserted in the core in the form of plates, impregnated solutions, or powders. In addition, moderator can be removed or added excessively, or the core can be made in two assemblies whose separation distance is varied.

The heat-removing agent can be used as a vehicle to introduce materials taking part in the process. The document also mentions the need for fission-product removal and refueling and states that radiations from the core have many applications, particularly in medicine.

Determining

Nuclear Fuel Requirements for Large-Scale Industrial Power

By JAMES A. LANE
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Total requirements of fuel plus fertile material in the projected industrial nuclear power program will be approximately the same over the next 50 years whether the plants use breeder reactors or the more efficient of the nonbreeder or converter reactors.*

This is because the fertile material added to the expanding system in the form of reactor inventories constitutes an important fraction of the total material requirement. And these inventories are more or less independent of breeding gain. Moreover, the fuel inventory requirements of breeder reactors might be higher than for converter reactors, and initially these requirements will have to be supplied from natural sources rather than by breeding. Thus converter reactors require less total material to initiate a nuclear power program than breeder reactors.

Bases for comparison of U. S. material requirements for various nuclear power systems are presented as analytical expressions that closely approximate estimates made previously.*

Growth of electrical capacity. If it is assumed that the installed electrical plant capacity will increase eight-fold during the next 50 years,† the growth can be represented by $C = C_0(1.043^T)$; where C = Mw installed capacity after T yr, and C_0 = Mw installed capacity at $T = 0$.

Taking $T = 0$ in 1960, T yr after 1960 C will be 131,000 (1.043^T).

Annual additions to electrical system. The annual additional capacity T yr after 1960 is found from the differential of the above equation, or

$$\Delta C = 5{,}500(1.043^T)$$

Annual additions to nuclear system. Assuming first, that there will be 500 Mw of installed nuclear electric capacity in 1960; and second, that half of all new plants built in the year 2000 will be nuclear plants, the rate of growth of the nuclear system will increase thirty-fold in that period. This growth rate can be represented in Mw/yr by

$$\Delta N = 500(1.09^T)$$

Installed nuclear electric capacity. The installed nuclear plant capacity in Mw at time T is found from the integral of the rate of growth as

$$N = 500 + \int_0^T 500(1.09^T)\,dT$$

$$= 5{,}800(1.09^T - 1) + 500$$

Annual inventory requirements. The amount of material required annually (tons/yr) for enriched fuel and for source material inventories is

$$\Delta I = (i_f + i_s)N$$

where i_f = fuel inventory per Mw installed electrical capacity, tons natural U equivalent per Mw, and i_s = blanket or source material inventory, tons U^{238} or Th^{232} per Mw.

The value of i_f depends on specific power, reactor type, thermal efficiency and efficiency of converting the U^{235} in natural uranium to Pu^{239} or U^{233}. Taking these factors into consideration, one gets the following values for fuel inventories: for fast breeder, i_f = 2.9 kg Pu/Mw = 0.8 short tons natural U/Mw; for thermal breeder, i_f = 0.8 kg U^{233}/Mw = 0.2 short tons natural U/Mw.

The value of i_s depends on the reactor geometry (i.e., one region vs. two region) and on the amount of heat generated in the source material. In the case of thermal converter-type reactors fueled with natural- or slightly-enriched uranium, the fuel and source material are combined and only one inventory requirement need be considered. This amounts to 0.2 short tons natural uranium per Mw electrical capacity. The value of i_s for fast and thermal breeders will also be approximately 0.2 short tons of U^{238} or Th^{232} per Mw, respectively.

Fuel bred annually. The production of new nuclear fuel by breeding depends on the breeding gain and the plant factor and is given by pN, where p is the fuel produced in kg per year per Mw installed capacity. Thus the number of tons produced per year at time T is,

$$\Delta P = pN = p[5{,}800(1.09^T - 1) + 500]$$

For assumed breeding gains of 0.4 and

* J. A. Lane, NUCLEONICS 6, **12**, 12 (1954).
† Palmer C. Putnam, "Energy in the Future," (D. Van Nostrand Co., New York, 1953).

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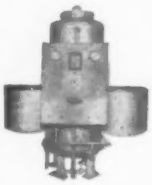

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0.1 for fast and thermal breeders respectively: for fast breeders, $p = 0.43$ kg/Mw year; for thermal breeders, $p = 0.144$ kg/Mw year.

The fuel doubling time is given by i_f/p. The net raw material required annually for fuel inventories is equal to $\Delta I - \Delta P$. After the time at which $\Delta I = \Delta P$, all fuel inventories can be supplied from bred material and there will be a surplus production of nuclear fuel.

Cumulative burnup in a converter. The cumulative burnup (tons of natural U) to time T in a converter reactor is given by

$$B = \int_0^T N\,dT = b[67{,}000(1.09^T - 1) - 5{,}300\,T]$$

where b = annual burnup per Mw installed capacity, tons natural U per yr, for 300 days operation per year.

Values of b depend on the uranium utilization, which is determined by the neutron economy, fuel lifetime and number of fuel recycles. Assuming that fuel is recycled after 5,000 Mwd/ton, b is: 0.80 when the initial regeneration ratio (clean reactor con-

Four Uses of a Zero-Power Reactor

When interested in examining only the nuclear aspects of a design for a reactor, one finds that he can build a cheap nuclear mockup—also called a critical assembly or a zero-power reactor—with no worries about temperature, radiation damage, heat transfer or corrosion. It is not necessary to contain pressure, confine radioactivity or provide for thermal expansion or fluid flow. Yet the fruits from such machines are many.

Let us consider four stages in the development of a reactor: conceptual design, engineering design, manufacturing and operation.

1. During conceptual design, the service of a flexible nuclear mockup—one that can be rebuilt with different arrangements of fuel—is invaluable. Data most easily determined with such a critical assembly include lattice parameters, fuel loading, control rod placement and programming, temperature coefficient of reactivity, and heat generation patterns. These numbers must be chosen before engineering parameters such as coolant flow and pipe sizes can be fixed.

During the very earliest stages of design, some of this work can be done on a mockup of less than critical size when used with a standard neutron source such as a radium-beryllium gun. Such a subcritical assembly, or exponential experiment, can save a lot of money but, of course, is less versatile than a full critical assembly. You will recall that more than a score of exponential experiments were built preliminary to the assembling of the first reactor in Chicago in the fall of 1942.

2. After the engineers have set the conceptual design of the large reactor, they use a less flexible and more detailed critical assembly. It helps to answer such questions as the effect of gaps and structural parts on heat generation and neutron flux patterns, the streaming of neutrons through coolant and instrument channels, shadowing effects of adjacent control rods and the effect of fuel burnout and fission product build-up on reactivity and power distribution.

3. During the manufacturing stage, a zero-power reactor can be used to check the reactivity of samples of materials intended for core parts. Whole fuel elements and control units can be tested before they are installed.

4. Even after the big reactor goes into operation, the need for a zero-power nuclear facsimile does not stop. For example, since the mockup can be instrumented much easier than the large reactor, operating problems that arise with the large reactor probably can be studied best by the mock-up.

—From speech by L. R. Hafstad, Director, Division of Reactor Development, USAEC, before Congress of Industrial Chemistry, Brussels, Belgium, September 16, 1954

taining only U^{235} and U^{238}) is 0.85, 0.050 when ratio is 0.90, 0.035 when 0.95, and 0.020 when 1.00.

NUCLEAR POWER

• **Convair** Division of General Dynamics Corp. has been operating a research reactor at its Fort Worth plant since early this year. Device is being used on development tests for nuclear-powered aircraft.

• **Cost of Lithium-7,** an excellent reactor coolant, is understood to have been reduced to near $300/lb as a result of large-scale separations processes (NU, Feb. '54, p. 78; Sept. '54, p. 79). Lithium-7 is considered to be better than sodium or NaK as a reactor coolant (NU, June '53, p. 29). Its slow neutron capture cross section is only about 33 mb; but its high cost when separated from the high-cross-section Li^6 (believed to be an H-bomb material) has discouraged reactor designers.

While trying to check cost figures and learn whether further reductions are imminent, NUCLEONICS had the following exchange with the Atomic Energy Commission:

Q: Is AEC using Li^7 as a coolant in any production or experimental reactors?

A: No comment.

Q: Is AEC considering use of Li^7 in connection with reactor experiments?

A: This is a low-cross-section material and AEC is always interested in testing use of promising materials either as a coolant or for other purposes in its reactors.

Q: Can you give an idea of the present cost of Li^7?

A: No comment.

• **Total investment** of nearly $38-million would be required to build Nuclear Power Group's (Am. Gas & Elect., Bechtel, Commonwealth Edison, PG&E, and Union Electric of Mo.) 50-Mw (electric) D_2O-moderated natural-uranium power reactor (NU, July '54, p. 50). This sum would cover: reactor and associated equipment, $11.7-million; reactor core and core fittings, $4-million; D_2O inventory, $12-million; turbogenerator, $8.8-million; and 600-acre site, $0.8-million.

Burnup of 1% would necessitate refueling a small portion of core every 5 months. Fuel elements would be in zirconium tubes. There would be four primary coolant loops, one regulating rod, and 30 combination shim and safety rods.

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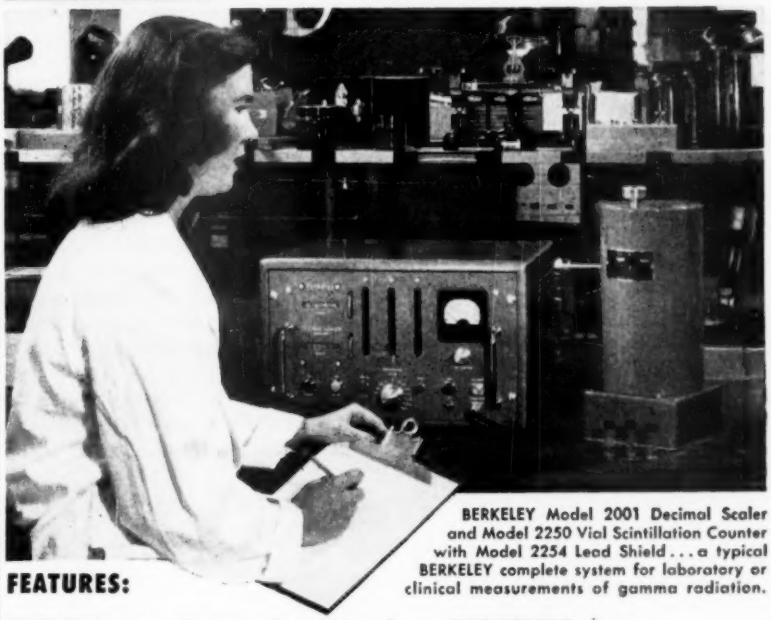

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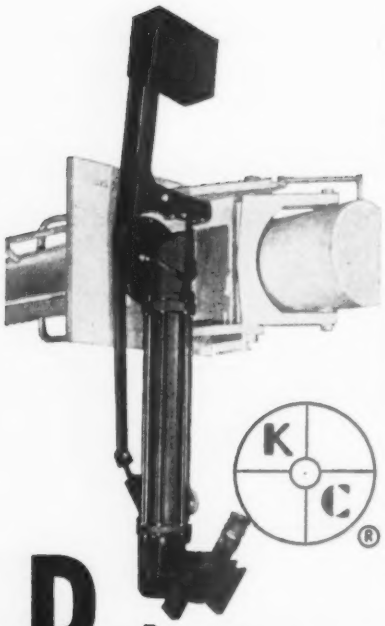

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TECHNICAL ADVANCES

Counting H^3 and C^{14}

Liquid scintillators that will count tritium and C^{14} more efficiently have been produced by University of California researchers D. J. Rosenthal and H. O. Anger. Xylene with terphenyl (5 gm/l) and diphenylhexatriene (0.015 gm/l) is their best scintillator. It will dissolve fatty acids and is miscible with a 5% solution of water in ethanol. Thus many labeled compounds can be counted merely by dissolving them in the scintillator-solvent. Typical counting efficiencies: C^{14}-labeled cholesterol, 70%; tritiated stearic acid, 32%; tritiated water, 16%.

Automatic Data Processing

Automatic recording of data on punched cards has permitted integration of experiment and subsequent computation of data in an extensive survey of slow-neutron cross sections underway at Brookhaven National Laboratory. Automatic data-taking equipment fixes the neutron energy (by setting the angle of a monochromating crystal spectrometer), positions the appropriate samples, programs various background counts, and provides for preset or fixed-interval counting by beam-monitor and detector. All of this data and more is recorded directly onto punched cards using a Remington Rand Numeric punch. Unattended operation of the entire experiment is thus possible.

The data-bearing punched cards are subsequently processed by a computer that analyzes the neutron resonances to determine their Breit-Wigner parameters.

Unusual Synchrotron

An Italian proposal for a variation in synchrotron designs could lead to 10 Bev machines without using strong focusing. The idea is to use a stepped pole piece, providing a wide gap in which the particles are accelerated to medium energies and a narrow gap to which they are then displaced for acceleration to 10 Bev. This design is made feasible by the smaller radial and vertical oscillations at higher energies; it is purported to save a factor of three in magnet costs. American accelerator designers are bearish, pointing out that the idea is not new and that field discontinuities themselves might induce disastrous oscillations.

Gamma-Ray Pinhole Cameras

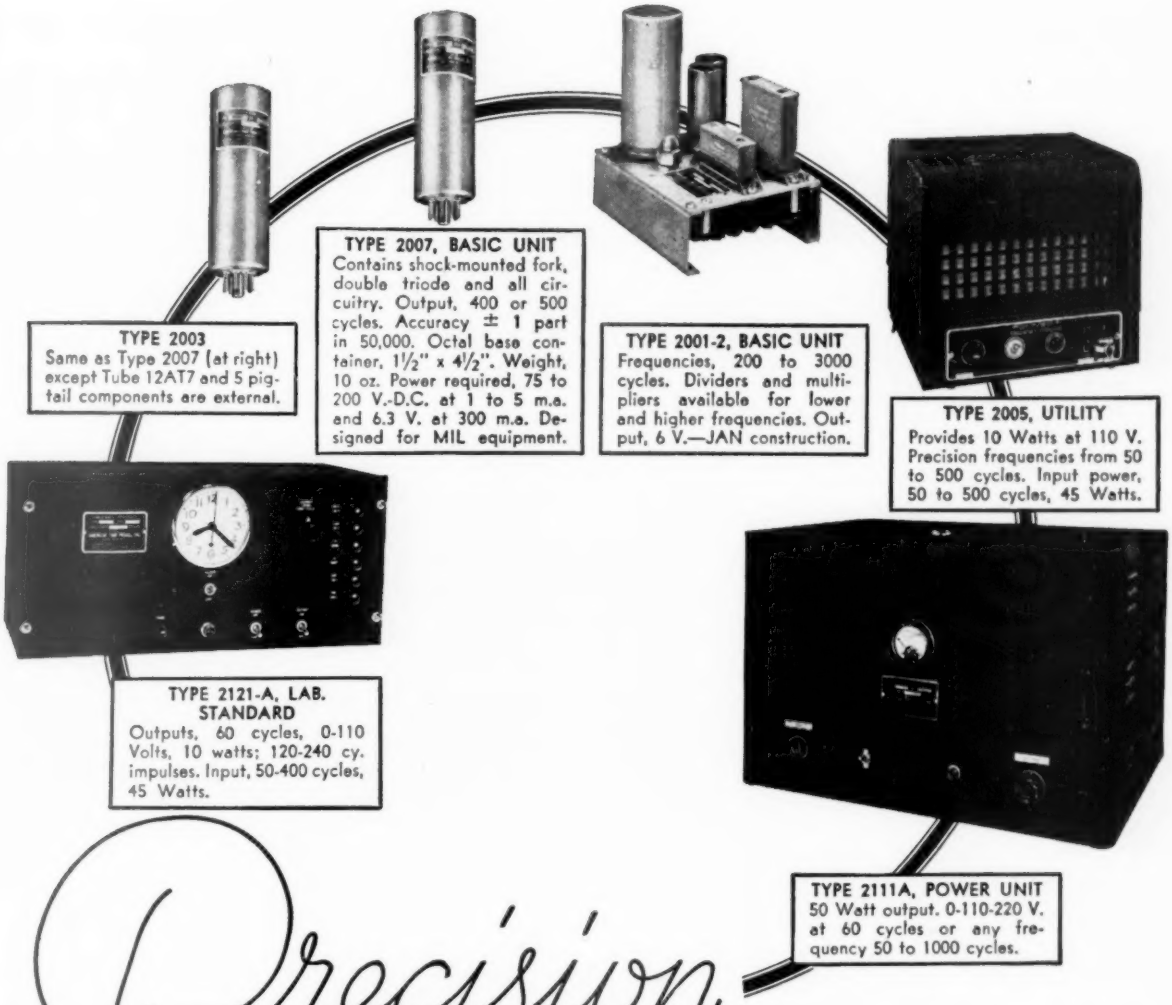
Roentgen made a pinhole camera as early as 1896; ever since, ways to increase the sensitivity without sacrificing resolution have been sought. To get images visible to the eye, Mortimer, Anger, and Tobias at Berkeley have employed a "view-plate" consisting of an image-intensifier tube faced with scintillation crystals. Sensitivity is such that two 200 $\mu c/cm^2$ sources, $\frac{1}{4}$ in. apart and 3 in. from the camera, can be resolved and made visible. This is an improvement over previous work, but is still inadequate for the ultimate goal of being able to view the *in vivo* distribution of radioactivity in patients.

A very promising system, they report, is under development at RCA. The combination of a high-gain multiple-stage light-amplifier tube and a television display is so sensitive that a single photon may be rendered visible.

Radiation-Effect Mechanisms

Radiation-induced changes in polyethylene's mechanical properties are well known, but underlying mechanisms have not been pinned down. To increase understanding of mechanical effects, Dole, Keeling and Rose of Northwestern University have made quantitative measurements of chemical changes using infrared absorption techniques. Bromine uptake gave a measure of the double bonds produced.

Their conclusions: approximately two double-bond groups are formed for one cross linkage; some C-C chains are broken; irradiation reduces the concentration of vinylidene unsaturated groups while producing vinylene unsaturation. This last is most important because unsaturated vinylene groups are the ones most likely to form crosslinks that affect mechanical properties. Previously, vinylene groups were not thought to occur. A long-range migration preceding cross linkage seems to be implied; but still under debate is whether it is molecular, ionic or electronic.



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BOOKS

Applied Atomic Energy

By K. FEARNSIDE, E. W. JONES, and E. N. SHAW (Philosophical Library, New York, 1954, viii + 156 pages, $4.75). Reviewed by CHARLES E. CROMPTON, Isotopes Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

In the introduction to this 150-page book, the authors state that it "endeavors to present [an outline] to the layman and to the scientific workers specializing in fields other than nuclear physics and nuclear chemistry." As a result of this effort to satisfy two divergent types of readers, the book emerges as one best suited for the science student. It is doubtful that the average reader of NUCLEONICS will find "Applied Atomic Energy" particularly informative.

The brief chapter, *Nuclear Reactors*, is particularly lucid in describing the basic principles of reactor design and operation. It is felt, however, that in the final pages there is expressed a somewhat overly pessimistic view of the future of power reactors.

The text also includes, as may have been anticipated, chapters on *Modern Nuclear Physics* and *Techniques* (instrumentation). The book is, of course, directed specifically toward British subjects and contains an appropriate chapter on legal aspects of atomic energy in England. The chapter on *Stable Isotopes* is excellent and presents a rather complete, albeit brief, picture of various separation processes employed in production as well as the scope of uses of stable isotopes.

The 9-page chapter, *Preparation and Distribution of Radioisotopes*, furnishes information useful to prospective customers, although brevity seems to be responsible for some misstatements. In mentioning the opportunities for special syntheses of radioactive compounds, only one United States firm is listed as performing this service while many more are actually engaged in this commercial activity. The opening paragraph of this chapter states that "the methods of preparation of isotopes are generally similar in all of these four places (England, France, United States, and Canada) but where any difference occurs this will be specifically referred to in the text." Only two pages later the preparation of iodine from irradiated tellurium is discussed with no mention of the process of recovering iodine from fission products as is done in this country. A further oversight is found in the last sentence of this chapter "The shipment of isotopes . . . has greatly increased over the past six months as will be seen in the figures for P^{32} and I^{131} issued by the Ministry of Supply and reproduced below." Figure 3 shows shipments for the years 1948, 1949, and 1950, whereas the date of publication is 1954. This chapter, as well as many sections of the book, could easily have been written two years ago as far as the timeliness of the information is concerned. This is not particularly objectionable, however, in view of the intended reading audience.

The authors have skillfully woven into their presentation many instances of historical significance. For example, the early work of Paneth is discussed briefly in connection with surface chemistry. Rutherford's classical spinthariscope is used to introduce the "contemporary" technique of scintillation counting and Hevesy's first application of radioisotopes to biology introduces the subject of metabolism.

The last five chapters encompass the use of isotopes in pure research, biology, medicine, agriculture and industry. The chapter on biology may well have been entitled *Radioisotopes in Human Physiology*. The introductory statement is made that "Fundamentally the value of biological research lies in the subsequent application to therapy. . . . " This chapter deals primarily with research on iron, phosphorus, and iodine metabolism and seems too closely allied to the chapter on medicine. One is left with the impression that a more representative chapter on biology would have better balanced the fields of science treated in the remaining chapters.

"The main purpose of . . . the chapter on medicine . . . is to discuss clinical rather than experimental techniques. . . . " Although a reasonable cross section of clinical uses is presented, one derives from this chapter neither an appreciation for the widespread efforts of the medical profession in exploring new radioisotope techniques nor the extent of established uses in present-day medical practice. A brief mention of the use of colloidal Au^{198} and the fifteen-line reference to the efficacy of I^{131} is illustrative of this point. The discussions are so conservative that the reader would be surprised to learn that 100,000 patients in this country had received diagnostic doses of I^{131} and 20,000 patients had received such treatment for hyperthyroidism.

The same general criticism may be made of the later chapter on industry. Over-generalization is a defect difficult to eliminate in the brief treatment of so many fields. There does not appear to have been an effort to present the latest uses in each field discussed, but rather we encounter again discussions of those classical uses that appear all too frequently in general survey articles. This, however, should not detract from the book's primary usefulness as a well written, compact, general introduction to this subject. This reviewer is hopeful that future texts on applied atomic energy will be directed at specific technical audiences and will include quantitative information on both feasibility studies and the ultimate uses themselves.

BOOKS RECEIVED

Noise and Stochastic Processes, edited by Nelson Wax, Dover Publications, Inc., New York, 1954, 337 pages, $2.00 (paperbound), $3.95 (clothbound). This book on random processes and their applications is the third volume in a series, each a collection of reprinted papers in a particular scientific field. These papers are mainly reviews on "noise," Brownian motion, and statistical mechanics with literature references up to 1945.

Nuclear Reactors for Industry and Universities, edited by Ernest H. Wakefield (president, Radiation Counter Laboratories), Instruments Publishing Co., Pittsburgh, 1954, ix + 93 pages. This book is a compilation of articles originally appearing in "Instruments" magazine. Subjects are: *Nuclear Reactor Types, Availability and Selection, Radioactivity Measurement, Radiation Protection, Reactor Control, Instruments for Experiments, Cost Study,* and *Legal Aspects.*

Alternating-Current Machines, by A. F. Puchstein, T. C. Lloyd, and A. G. Conrad, John Wiley and Sons, Inc., New York, 1954, xii + 721 pages, $8.50. This revised, third-edition textbook includes new material on vector treatments, synchronous motors, alternators, and rectifiers.

Perceptualistic Theory of Knowledge, by Peter Fireman, Philosophical Library, Inc., New York, 1954, xi + 50

pages. $2.75. The purpose of this book is perhaps stated most succinctly in its conclusion: "We made a quick excursion into rationalism in order that, by seeing its groundlessness, we be more contented with our empiricism. Suppose then that we accept our perceptual cognitions and the conceptual knowledge based on them, as a *Perceptual (Perceptualistic) Theory of Knowledge*, to replace the so-called sensationalistic theories."

ALSO OF NOTE

Patent Abstracts No. 1—Instrumentation. First of seven volumes on government-owned inventions to be published this year, this book lists 775 inventions under the subgroups: laboratory, scientific and engineering instruments; instruments for indicating, measuring, and recording electrical quantities and characteristics; mechanical measuring and controlling instruments; optical instruments and lenses; surgical and medical instruments; X-ray and therapeutic apparatus; surgical and orthopedic appliances and supplies; photographic equipment and supplies. Abstracts include description, patent number, title, inventor, and administering government agency. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., $2.00.*

Prospecting with a Counter. This AEC booklet, companion reference to "Prospecting for Uranium," provides detailed discussion of radiation detection instruments. It is a revised version of AEC report RME-4028 by R. J. Wright. Emphasis is on practical problems related to field use. *U. S. Government Printing Office, Washington 25, D. C., $0.30.*

A Handbook on Mass Spectroscopy. This handbook, by M. G. Inghram and R. J. Hayden, is Nuclear Science Series Report No. 14. Among a variety of mass analysis techniques, handbook discusses microwave absorption and nuclear induction, confined to ionic mass analyzers with electrical or photographic ion detection. *Publications Office, National Academy of Sciences-National Research Council, 2101 Constitution Ave., Washington 25, D. C., $2.00.*

Nuclear Notes for Industry, No. 2. Current selected AEC unclassified reports of interest to industry are listed and abstracted. *Technical Information Service, Oak Ridge, Tenn.*

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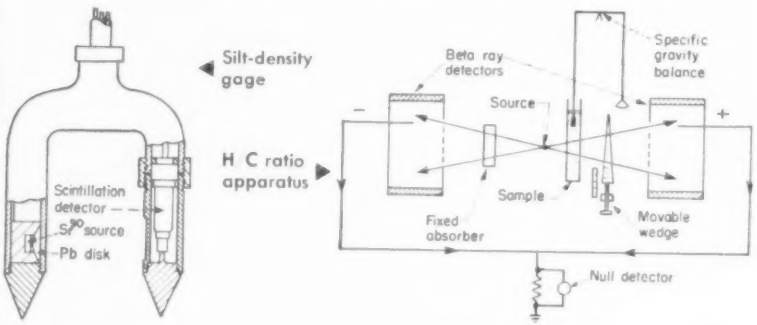
Need for drift of only ½% per day in continuous measurement and control of tobacco flow rate lead to use of Sr^{90} beta gage. Previously, dielectric gage had been used for finished cigarettes, but was not adaptable to controlling tobacco flow and was too moisture sensitive. In new setup, comparison of output from identical isotopes and ion chambers, with standard cigarette between one set and production feed between other, yields signal that controls tobacco feed rate. Isotope gage output also zeros dielectric gage that ejects off-quality cigarettes. American Machine and Foundry Co. developed new installation.

Dye Carryover Protection

In multicolor textile printing operations, persistent trouble has been caused by previously applied dyes being carried over by the cloth into a second dye bath. Fractions of a per cent can seriously affect second dye. Continuous monitoring to guard against dye transport is done by adding soluble P^{32} to offending dye bath; dip counters at baths down printing line warn of any contamination. No health hazard is introduced; only few μc per week is added, fabric is washed at later step, and P^{32} has two-week half-life. Carolina Textile Engraving Co. is negotiating to act as U. S. agent for British developers.

Silt-Density Gage

Measuring silt content at bottom of lakes involves major access and sampling problem. Low-energy isotope gage could be used, as transmission ratio of water to soil is 10^3 for 50-kev gammas, but no isotope meets requirements of low energy, long half-life and ready availability. Therefore, AEC Isotopes Division developed use of bremsstrahlung radiation from Sr^{90} β-rays on lead. Device measures and records silt content, at any depth, of moving streams or lakes.



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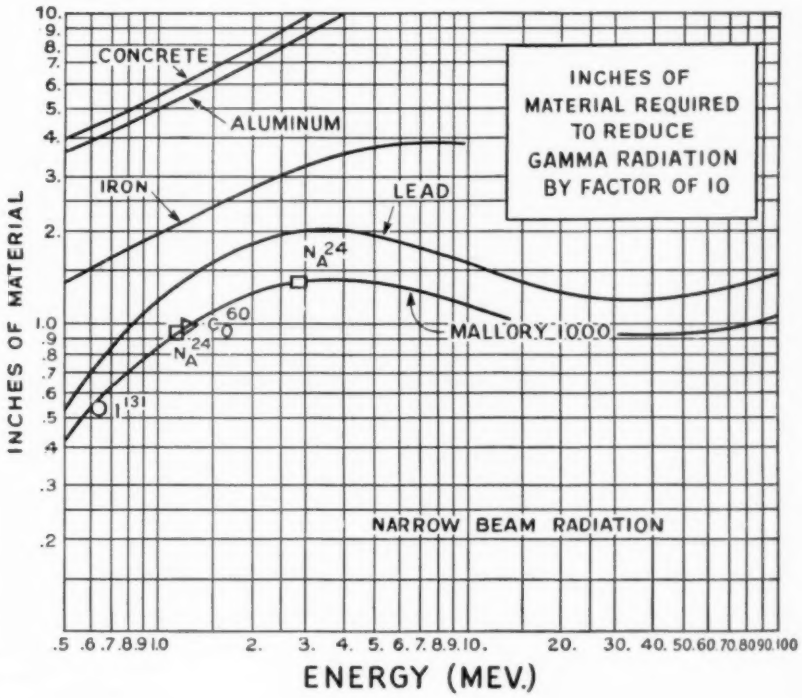
* Based on material presented by Charles Crompton, Asst. Director, Isotopes Division, USAEC, at Ann Arbor, June, 1954.



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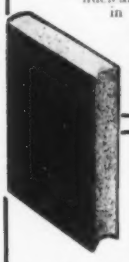

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LETTERS

Isotope Comparison

DEAR SIR:

In the News section of the August issue of NUCLEONICS we noted that "Britain passes U. S. in Shipping Isotopes." Being directly associated with the U. S. distribution program it was clearly evident to us that the comparison on pages 57–58 was a casual one. The annual radioisotope sales at Oak Ridge National Laboratory, which is operated by Carbide and Carbon Chemicals Company, are over $1,300,000 and lead to many millions of dollars more in related business, as recently pointed out in a talk by AEC Commissioner Joseph Campbell. The U. S. radioisotope business is definitely not smaller than Britain's, and the following information should serve to establish [a] proper perspective . . .

The shipping figures of the two countries reflect basic differences in philosophy; such differences not only deserve clarification but should be emphasized. The United States has encouraged private business concerns to do special processing of isotopes, fabricate special sources, synthesize labeled compounds, etc. The portions of the radioisotope business that must be done by a single production center for economical operation has been and still is being operated at Oak Ridge National Laboratory on a business-like basis at no operational cost to the U. S. taxpayer; those secondary operations that can best be performed by private enterprise are being done by American business institutions.

As a measure of the success of the program to obtain participation by private enterprise, it should be noted that there are about 30 commercial "secondary suppliers" in the United States. *Two* such suppliers account for a combined total of more than 15,000 shipments a year, clearly reversing the picture in NUCLEONICS. Shipments from other AEC facilities such as Brookhaven and Argonne exceed 1,000 per year, and with the recent entry of the MTR and Argonne's new CP-5 these figures are expected to grow substantially.

It should be noted that over 300 isotopically-labeled compounds are available in this country from commercial sources, whereas in Britain such materials are synthesized in the government-owned Radiochemical Centre at Amersham. The Radiochemical Centre is also, to our knowledge, the only English fabricator of sealed radioactive sources for use in industrial gages, whereas in the United States approximately ten private firms are engaged in this type of source fabrication.

The number of shipments is not necessarily a good index of the amount of business being done. Many of the British shipments are small—in the range of microcurie to a few millicuries per shipment. However, at ORNL the shipments are tending to be more of the "wholesale-type," containing thousands of millicuries per shipment.

As further evidence of the participation of private enterprise in the radioisotope business, we are gratified that while the number of shipments is not rising markedly the amount of activity shipped is rising rapidly. Your readers may be interested to learn that the total activity shipped since the inception of the U. S. isotope distribution program is roughly 35,000 curies (as of June 30, 1954); the present annual rate is about 10,000 curies. Co^{60} of course accounts for a large amount of the activity sold, approximately 25,000 curies thus far. Nevertheless, considerable quantities of other radioisotopes are being shipped; for example, more than 500 curies of I^{131} per year.

—A. F. RUPP
Superintendent, Operations Division
Oak Ridge National Laboratory

—CHARLES E. CROMPTON
Assistant Director, Isotopes Division
U. S. Atomic Energy Commission
Oak Ridge, Tennessee

Wrong Reactor, Right Company

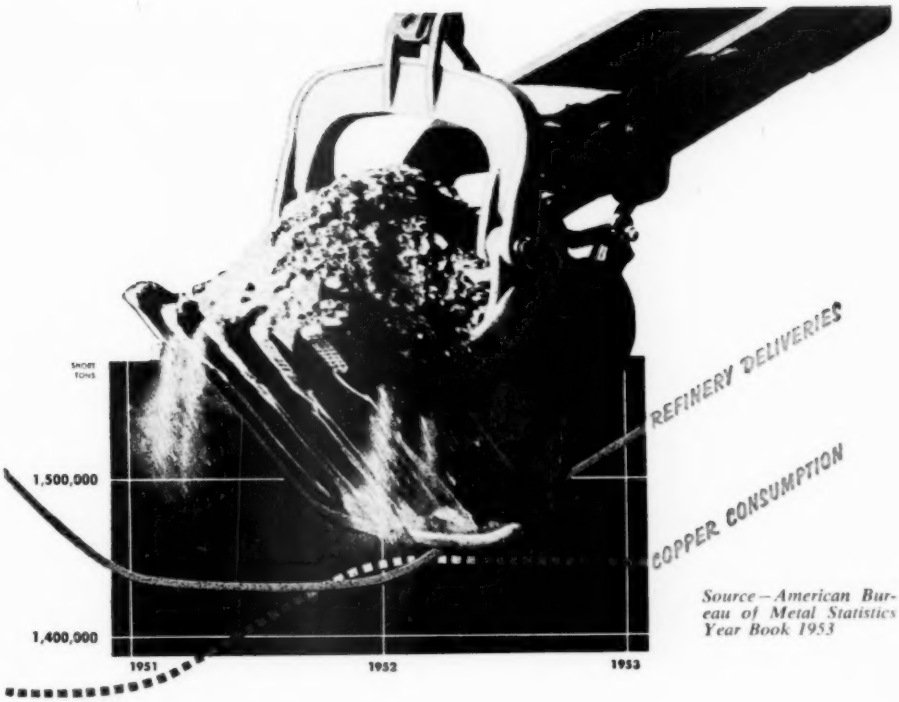
DEAR SIR:

In your review of the Washington, D. C. meeting of the Atomic Industrial Forum (NU, July '54, p. 48), the abstract of the Pioneer-Foster Wheeler-Diamond Alkali statement contained some errors which I thought you might like to know about.

. . . You indicated that we included low cost structure as a potential advantage of the circulating-fuel thorium breeder. Actually, this reference was to our study of a fluidized-solids reactor system.

Likewise, the reference to loss of stability refers to the fluidized-solids reactor and not the thorium breeder. Actually, the circulating-fluid-fuel thorium breeder is a reactor system we view with favor.

—C. R. BARTHELEMY
Chief Mechanical Engineer
Pioneer Service & Engineering Co.
Chicago, Illinois



Source—American Bureau of Metal Statistics Year Book 1953

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More copper keeps on coming. Eleven major new projects in the U. S. will start producing in the next 3 years. These mines will add 250,000 tons to our annual production—more than *¼ of all the domestic copper mined during 1953.* In addition, recent improvements in mining techniques now make it possible to obtain copper from ores considered commercially unworkable in the past.

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Foreword, U. S. Dept. of Commerce B.D.S.A. Copper Quarterly, August 1954

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NEWS

Libby Named to AEC as Smyth Resigns

President Eisenhower has named Willard F. Libby to the Atomic Energy Commission to replace Henry D. Smyth. Dr. Smyth resigned from the Commission to return to Princeton University as chairman of the board of scientific and engineering research, a newly established post aimed at coordinating scientific and engineering research at the university.

Smyth's resignation came as no surprise; last February he told AEC chairman Strauss that he would resign this fall. When Smyth left on Sept. 30, his May, 1949, appointment still had 21 months to run.

Libby's appointment is an interim one; but approval by the Senate when it convenes in January should be routine. As the scientific member of the Commission, Libby can draw on experience including work with the Manhattan Project, six years as a member of AEC's committee of senior responsible reviewers, and membership on the AEC general advisory committee.

The new Commissioner, 46 years old, received his doctorate from University of California at Berkeley in 1933. He was a faculty member there until he joined University of Chicago's Institute for Nuclear Studies in 1945. The radiocarbon method of dating was originated by him.

U. S. Reports to UN On International Plans

A four-point proposal for peaceful international atomic energy activities was introduced at the opening of the United Nations General Assembly last month by Secretary of State John Foster Dulles. Although few details were given, the plan is intended to implement the ideas set forth by President Eisenhower before the UN on December 8, 1953, and in his Labor Day speech.

Mr. Dulles indicated that the U. S. intends to report to the UN later on its efforts toward:

1. The creation of an international agency, whose initial membership will include nations from all regions of the world. It is hoped that work will be started next year.

2. The calling of an international scientific conference on the whole subject of nuclear energy, to meet in the spring of 1955 under UN auspices.

3. The opening in early '55, in the U. S., of a reactor training school where foreign students may learn "the working principles of atomic energy with specific regard to its peacetime uses."

4. The invitation to a substantial number of medical and surgical experts from abroad to participate in the work of U. S. cancer hospitals.

Informal talks on the international pool have already been held with Britain, Canada, Belgium, France, Australia and South Africa. It is not yet clear whether an international laboratory will be set up, with fissionable materials to be contributed by certain member nations, or whether the agency will be solely for the purpose of exchanging information.

W. F. Libby, new member of AEC

Belgium Signs Swiss Pact; to Trade Data, Uranium

With a wartime agreement giving the United States and Great Britain a virtual monopoly on Belgian uranium ores now expired (NU, Aug. '54, p. 56), Belgium signed a pact on Sept. 18 to trade uranium and data with Switzerland. Under the new agreement, information on power reactors the United States gives to Belgium may eventually be channelled to Switzerland.

Belgian-U. S. talks on ore supplies and power-reactor data have produced no new agreement to date, even though they are implemented by being tied both to a major source of uranium, the Belgian Congo, and to President Eisenhower's atomic pool plan. Actually, the pool plan doesn't offer much advantage to Belgium; with its uranium, it is in a good bargaining position.

Supplying U. S. nuclear data to foreign countries was forbidden under the McMahon Act, so Belgium never got the data it was entitled to under the wartime agreement. With the new Atomic Energy Law, Belgium wants the information and processed fissionable materials it needs to build its own power reactor.

The Belgians are understood to be primarily interested in design information for a pressurized water reactor like PWR, or other systems using only slightly enriched fuels. Belgium does not have gaseous diffusion facilities needed to produce usable amounts of highly enriched uranium.

New Group Offers Nuclear Lab Services

Nuclear Science and Engineering Corp. has been organized to provide a service and experimental laboratory for the nuclear industry. According to its president, Ronald A. Brightsen, the new Pittsburgh, Pa., company will concentrate on nuclear and radioactivity measurements and nuclear chemistry. It will do no instrument manufacturing or reactor design work.

Equipping of NSEC's first radiochemical laboratory is almost complete. Additional experimental facilities are planned for the near future.

The company is organizing into four divisions: chemistry, physics, engineering and biology. Typical of the type of services it will perform are reactor flux measurements, heavy-element chemistry, industrial radioactivity application feasibility and design studies, and experiments connected with nuclear power plants.

Gordon Dean, former Atomic Energy Commission chairman now with Lehman Brothers, is chairman of the board. Ralph L. Ely is vice president and technical director; Richard S. Frankel is secretary-treasurer. Other members of the board are Glenn T. Seaborg, University of California; Manson Benedict, Massachusetts Institute of Technology; Truman P. Kohman, Carnegie Institute of Tech-

nology; Freeman H. Dyke, The American Metal Co., Ltd.; Morris F. Ketay, president of Ketay Manufacturing Co.; and William H. Osborn, Lehman Brothers, a New York investment firm. The last three represent companies underwriting the new firm.

Associate scientists with NSEC are Charles D. Coryell, MIT, and Kohman.

Suggests Reactor for Japan, Critical of U. S. Program

In one of the frankest speeches by a member of the U. S. Atomic Energy Commission, Thomas E. Murray was critical last month of the U. S. civilian nuclear power effort and called for tangible proof of our peaceful intentions on the international scene. As evidence of the latter, he suggested that the U. S. offer to build nuclear power plants for various nations. He named Japan as the first place he would build one.

The State Department reported earlier this year that, in Japan, "the average electric power production costs of public utility thermal plants in 1952 were close to 20 mills per kwh, of which coal costs contributed approximately 15 mills. This figure is among the highest of any of the industrialized countries of the world." There appears to be little doubt that nuclear power could be competitive in Japan today.

Murray pointed out that, despite the fact that there is no urgency today in this country for economic nuclear power, an all-out effort should be put into the program and that a failure to do so would be a "dog in the manger" attitude. He said, "We should immediately increase the number of scientists who are engaged in atomic power work."

In criticizing the limited U. S. effort, Murray said, "There are no operating power reactors in this country today (except for the submarine prototype in Idaho). . . . Candor requires that we distinguish between achievement and promise . . . We must not identify promising development programs with operating reactors . . . Part of the reason (for our lack of progress) has been our necessary preoccupation with improving and stockpiling atomic weapons. It must be admitted however, that we could have done more in spite of Soviet intransigeance. Indeed, our one operating unit would not be in existence today if it had not offered great military promise. . . . Even our first major step toward industrial nuclear power, the Shippingport 60,000 kw reactor, was only salvaged after much persuasion from an abandoned naval design."

In his talk, Murray cast a negative vote against the controversial dual-purpose reactor (for production of weapons-grade plutonium and power) that has been proposed to AEC by several companies. He said that "the Government already has in operation and under construction sufficient facilities to supply present military requirements for weapons-grade plutonium. Even if military requirements are increased it is highly unlikely that (such plants) could be depended upon to meet firm military requirements for the critical years ahead."

Rockefellers Buy Interest in Nuclear Firm

A minority interest in Nuclear Development Associates, Inc., White Plains, N. Y., has been acquired by Laurance and David Rockefeller. They will be represented on the board of directors by Harper Woodward and T. F. Walkowicz, thus increasing the board to nine members.

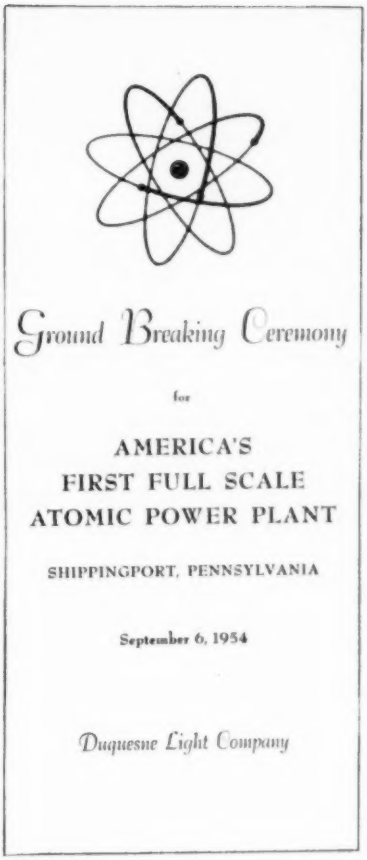
NDA was formed in 1948 by John R. Menke and Gale Young, present president and technical director, respectively. The firm's main activity is design, development and construction of nuclear reactors.

Nuclear Power Company Wants New England Plant

Location of an experimental nuclear power plant in New England at an early date is the aim of a new company formed by 11 utilities serving the area. Yankee Atomic Electric Co. has asked the Massachusetts department of public utilities for the preliminary approvals needed for incorporation in that state. The group has already started discussion with the Atomic Energy Commission.

Just how the project will work out depends on AEC's interpretation of the Atomic Energy Act of 1954. AEC might split the cost of an experimental plant with the group; thus no decision has been made on the company's investment.

President of the new company is William Webster, vice president of New England Electric System. Other utilities backing the new company are: Boston Edison Co., Connecticut Light & Power Co., Western Massachusetts Electric Co., Public Service Co. of New Hampshire, Eastern Utilities Associates, New England Gas and Electric Association, Central Vermont Public Service Corp., and Central Maine Power Co. These companies represent over 90% of electric output in the six-state area. They plan to buy and distribute the entire output of the proposed nuclear project.



PROGRAM commemorates ceremonial start of construction of AEC-Duquesne-Westinghouse nuclear power plant. But on-site work won't really boom until next March, with March, 1957, the target date for completion. Entire primary system, including heat exchangers, will be enclosed in steel shell to retain any possible radioactivity; steam plant will be underground in concrete structure. Reactor will be enclosed in container 9 ft in diameter, 25 ft high that won't be filled by 6-ft diameter, 7 ft high Westinghouse-built core. Larger cores may be used in future

GE Forms Unit to Market Atomic Power Equipment

The General Electric Co., Schenectady, N. Y., has formed an Atomic Power Equipment Component (sub-

Sidelights

Illinois Tech starts nuclear engineering course. Dr. Walter Fagan is teaching a four-credit-hour graduate course in nuclear engineering this semester at Illinois Institute of Technology, Chicago. Introductory course covers fundamentals, reactor theory and operation, personnel protection, radiation damage and chemical processing.

●

Mexico starts dating. University of Mexico opened a radiocarbon dating laboratory in September. Directing the new project is A. Moreno y Moreno, who studied the age-determining technique with W. F. Libby at the University of Chicago.

●

AEC spending $2.2-billion in fiscal '55. Budget Bureau's estimate of Atomic Energy Commission net expenditures in fiscal 1955 are $307-million higher than 1954.

●

How to use autoradiography in biology. Britons can learn theory, practice application of autoradiography in special course at Atomic Energy Research Establishment's Isotope School, Harwell, Dec. 13–16. S. R. Pelc of Hammersmith Hospital will direct the course.

●

Reactor engineers: 76 more diplomaed. Oak Ridge School of Reactor Technology graduated 76 students in August, raising total number of graduates to 290. In this fourth class were 18 AEC and contractor employees, 20 from other government agencies and contractors, 9 from industry, and 29 recent college graduates.

●

U. S. can cut 5 years from Latin atomic power program. Robert LeBaron, touring South America on a State department goodwill mission, opened a U. S. exhibit at the Sao Paulo Exposition in Brazil with the statement that by supplying fuel elements and other critical parts for power reactors, the United States can save five years in South American atomic power development.

●

Atomic stomach ache? Soldiers can blame vets. With few animals left in today's mechanized army, prime responsibility of Veterinary Corps officers is determining wholesomeness and quality of foods for troops. Now Defense Department is sending its veterinarians to Oak Ridge Institute of Nuclear Studies for two-week course in effects of radiation on foods and animals. First course started in September.

●

Nautilus gets pennant. The long streaming pennant denoting a ship in commission was hoisted to the mast of the United States' first atomic submarine on Sept. 30. Steam-pipe failure during preliminary tests will delay sub's joining Atlantic fleet.

●

Richter jailed. Ronald Richter, former chief of Argentina's atomic energy project, spent five September days behind bars for contempt of Congress.

●

Vitro Uranium Co. making a profit. New provisions of its AEC contract have enabled Vitro's subsidiary processing company to operate profitably. The division has stockpiled more than $800,000 worth of uranium ore and has increased throughput by 48%. More than $300,000 has been appropriated for improvements in the mill.

●

Rutgers will open radioisotope training center. Financed by $1,000 memberships from New Jersey industries, a radioisotope center is planned for Rutgers University. Training of students and industry representatives in use of radioisotopes in research will begin in February. Chairman of the planning committee is Frank G. Dunnington, professor of physics.

●

Atom plus heat wins $250. Using a nuclear energy symbol superimposed on a representation of the Carnot thermodynamic cycle to symbolize the effect of present and past on the world in which we live, A. T. Lemmens designed the winning symbol for the American Society of Mechanical Engineers 75th anniversary next year. He won $250.

division) to market such equipment for commercial use. The new unit will engineer, manufacture and sell low-power reactors, reactor systems, heat transfer and cooling system components, safety and remote-handling devices for radioactive materials, and other related nuclear reactor equipment.

Originally organized to supply products and services to the company's Atomic Products Division, the new group will work closely with it. The older division was established in 1953 to centralize administration of operations at Hanford, Knolls Atomic Power Laboratory, and the Aircraft Nuclear Propulsion department.

Two managers have been transferred to the new group. Donald Eldred, formerly with apparatus sales division, is manager of atomic power equipment sales. Howard E. Grantz, formerly at KAPL, is manager of atomic power equipment engineering.

Armour to Build Reactor for Industrial Research

Plans for a 50-kw research reactor are being submitted by Armour Research Foundation, Chicago, to the Atomic Energy Commission for approval. The $500,000 water-boiler-type unit will be located in a new building on the Illinois Institute of Technology campus in downtown Chicago.

As a safety precaution, the reactor room will be a gas-tight steel tank about 60 ft in diameter and 25 ft high.

The proposed unit will be used solely for unclassified industrial research; it will not be used for educational instruction or college research. It will provide a neutron and gamma-ray source for irradiation experiments, for activation analysis, and for producing short-lived radioisotopes.

The Foundation will assume about one-third of the investment. Chicago industries are being invited to participate with $20,000 subscriptions.

Westinghouse Changes Atomic Power Unit

Realigning its atomic power division, Westinghouse Electric Corp. has placed two reactor projects under managers reporting directly to Charles Weaver, division manager. Each project manager will have direct responsibility for meeting his project's objectives.

John W. Simpson becomes manager of the pressurized water reactor project

(PWR). He formerly was assistant division manager.

John T. Stiefel becomes manager of the submarine thermal reactor project (STR). He formerly was manager of the engineering department, thermal design section.

In another appointment, W. D. Shepherd was named sales manager of the division. He formerly was contract manager.

Name McPherson Co. for ORR Planning

Architect-engineering work on the building and shield structure of the high-flux Oak Ridge research reactor (ORR, see NU, Sept. '54, p. 36 for description) will be handled by the McPherson Co., Greenville, S. C. The work will be done by subcontract under Union Carbide and Carbon Corp. (NU, Sept. '54, p. 5), operator of Oak Ridge National Laboratory.

Selection of a construction contractor on a lump-sum bid basis probably will not be done before next year. The $2.8-million research reactor is to be completed by 1957.

In conjunction with ORR, a new $700,000 laboratory will be built for study of effect of radiation on solids. Architect-engineer is H. K. Ferguson Co., Cleveland, O. A contract for construction of the 92 by 80 ft, 2-story building will be awarded on a competitive lump-sum bid basis.

AEC Wants New Quarters Outside Washington

The Atomic Energy Commission is well on its way to getting a new $9.5-million office building big enough to house its entire headquarters staff. Construction of the proposed building should start within the next nine months, on a site to be acquired outside the District of Columbia.

AEC Washington personnel now are scattered among three buildings in Washington. Chairman Lewis Strauss convinced the House public works committee that a single building is needed urgently to simplify security control and improve efficiency. The committee agreed to approve the AEC building project under a recently enacted lease-purchase law that permits the Government to acquire new buildings on what amounts to an installment plan.

Approval must be obtained also from the Budget Bureau and the Senate public works committee. Because the

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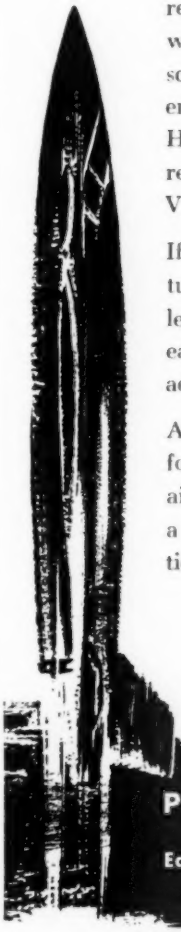

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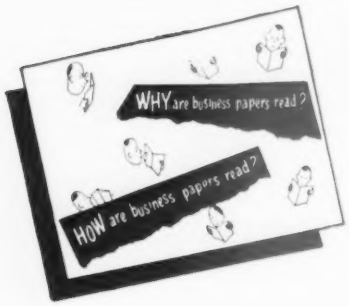

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lease-purchase program is new, the Budget Bureau is expected to take some time in deciding on the first projects submitted. But both the bureau and the Senate committee will act this fall.

Argonne Offers Temporary Research Jobs

Members of university and college faculties can apply for temporary research appointments at Argonne National Laboratory as late as Dec. 15. Appointments are usually for about one year, although shorter periods including the summer are considered when useful work can be accomplished.

Positions are available in biology, chemistry, engineering, medicine, metallurgy, and physics.

Applications and information are available from J. C. Boyce, Associate Laboratory Director, Argonne National Laboratory, Box 299, Lemont, Ill.

Plan Five Phases for National Planning Study

National Planning Association's $200,000 study of nonmilitary uses of atomic energy (NU, Sept. '54, p. 80) will concentrate on five major topics. Ten to fifteen studies dealing with these topics will be assigned to technical specialists and consultants; several additional studies will be prepared by the organization's staff.

The topics are: 1. National interest—role of nuclear fuels in relation to other sources of energy; effect on mechanization and automation of industry; best reactor types for power requirements; effects on other fields and national policy. 2. Regional interests—can power problems of regions like New England be solved? 3. Industrial interest—industrial requirements, organizational patterns, possible dislocation, role of small and large research groups. 4. Government-business relations—respective roles at various stages of power development, probable economic effects of new law, especially patent and licensing provisions. 5. International needs and problems—foreign economic effects, prospects of peacetime atomic programs, methods of cooperation and international financing.

Prior to embarking on this study in conjunction with Resources for the Future, Inc., NPA conducted a $5,000 preliminary feasibility survey.

Offer Fellowships in Medical Research

Division of Medical Sciences of the National Academy of Sciences-National Research Council will accept applications until December 10 for 1955–1956 postdoctoral research fellowships. Pro-

grams include fellowships in cancer research, British-American exchange fellowships in cancer research, fellowships in the medical sciences, tuberculosis, and radiological research.

Information and application blanks can be obtained from the Fellowship Office, National Academy of Sciences-National Research Council, 2101 Constitution Ave., N. W., Washington 25, D. C.

North American Building New Nuclear Lab

If a rezoning application for a Canoga Park, Calif., site is approved, North American Aviation, Inc., will start construction this fall of a new nuclear physics research laboratory. The new building will provide 80,000 square feet for projects including development of small research reactors.

Nuclear physics operation will add 100 personnel to its present staff of 400 when it moves from the company's Downey, Calif., plant. The new laboratory is scheduled for completion in July, 1955.

One factor in selection of the site is its nearness to the Santa Susanna mountain location where NAA will build a $10-million reactor as part of the Atomic Energy Commission's power reactor development program.

AEC Revises Regulations for Stable, Radioisotopes

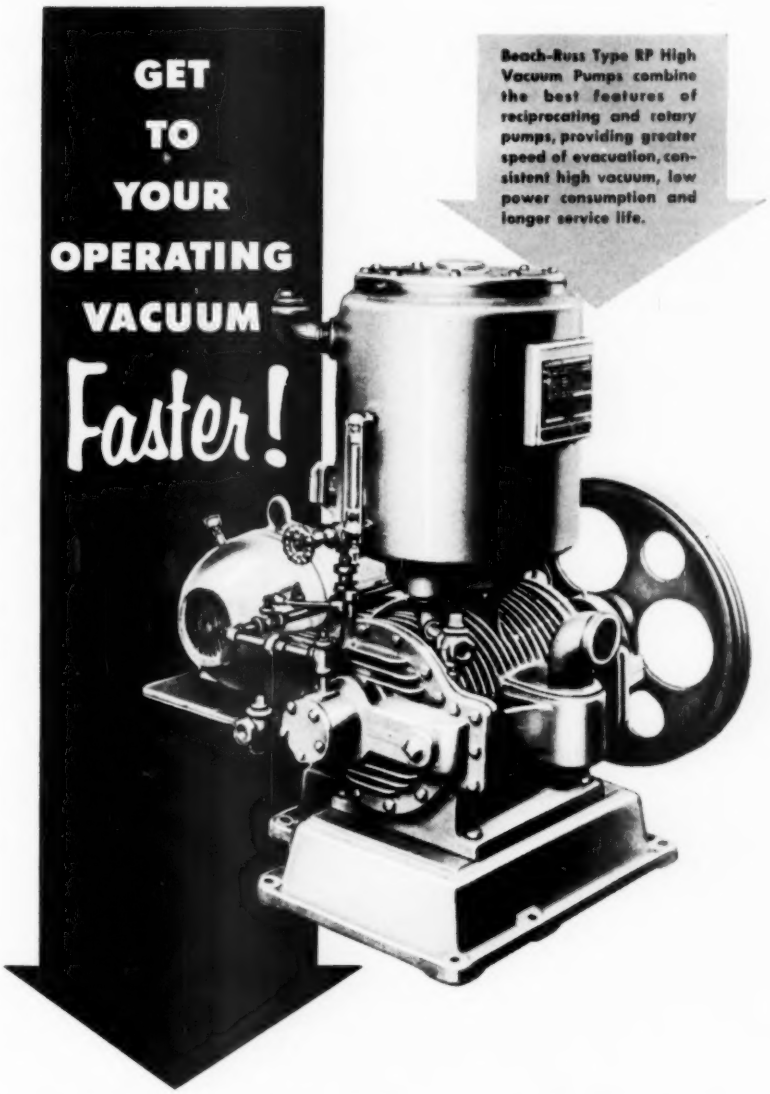
Broader control of radioisotopes to insure radiological safety has been created by one revision of Atomic Energy Commission regulations. At the same time, distribution of stable isotopes has been widened by approval of foreign shipments.

Radioisotope distribution regulations are extended to include products of any nuclear reactor in United States territory, whether public or private.

Foreign distribution of AEC-produced stable isotopes will follow the same procedures now applying to radioisotope requests.

RAW MATERIALS

United States: AEC shifts office, stops circular 7 leases. New York office of AEC's Division of Raw Materials has been transferred to Washington, D. C. Phillip L. Merritt will continue to direct domestic and foreign uranium exploration programs formerly handled by the office. AEC has also announced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the Dec. 12 end of the domestic uranium leasing program provided by circular 7. The circular made it possible to lease certain restricted public lands for uranium mining, but provisions in public law 585 supersede it. New law also provides for validation of mining claims located prior to Feb. 10 on public lands.

Canada: new processing plant contracted. Catalytic Construction of Canada, Ltd., will engineer and build facilities for new uranium refining process at Eldorado Mining and Refining Ltd's Port Hope, Ontario, plant. Estimated cost is $2.5-million; completion is scheduled for 1955.

Colombia: title a problem in new ore area. First large radioactive mineral deposits found in Colombia, is 80 miles northeast of Bucaramanga. Tests by U. S. AEC of the mineral, which appears in a copper compound mixed with gold and silver, indicate that it is economically exploitable. But two problems exist; irregularity of deposits (being studied by geologists), and confused titles to mining rights (dating back to colonial times).

Japan: develop ore process. Process for extracting 85% of uranium from poor host minerals such as apatite, mozite, illuminite, monazite, zircon, has been developed by S. Nishimura of Kyoto University. Waste fluid from phosphoric acid production yields uranium to organic compound; impurities in uranium extracted from compound are eliminated by precipitating uranic acid soda with alkali. Refining precipitate gives pure uranium.

Australia: start Rum Jungle plant. Treatment plant producing uranium oxide concentrate from ore went into operation on Sept. 17 at Rum Jungle, 30 miles south of Darwin.

NEWSMAKERS

W. C. Hall has succeeded E. H. Krause as associate director of research for nucleonics at Naval Research Laboratory, Washington, D. C. Hall formerly was superintendent of the solid state division.

John R. Dunning, Columbia University dean of engineering, has been appointed to the technical and engineering committee of the Dow Chemical-Detroit Edison atomic power project.

V. D. Nixon, formerly manager of process engineering for General Electric

at Hanford, has transferred to Schenectady, N. Y., as manager of the SIR reactor engineering section.

James G. Beckerley, formerly director of classification for AEC, has joined the research laboratory of the Schlumberger Well Surveying Corp., Ridgefield, Conn. The company, whose primary concern is well logging, uses nuclear techniques in its geophysical activities.

W. C. Moore has joined the Oak Ridge National Laboratory staff as project engineer for large-scale power-reactor design in the Homogeneous Reactor Project. He formerly was assistant chief engineer in charge of development engineering at the K-25 gaseous diffusion plant. **R. B. Briggs** has been named associate project engineer for this phase of the HRP.

Wade Thomas Batson is on leave of absence from the biology department, University of South Carolina to serve as assistant in the University Relations Division of Oak Ridge Institute of Nuclear Studies.

Charles L. Dunham, chief of the medical branch in AEC's Division of Biology and Medicine since 1949, has been appointed deputy director of the division.

Robert W. Hartwell is now director of the nuclear power development department of the Detroit Edison Co., after being assistant director.

MEETINGS

November 12–13: National Symposium on Quality Control and Reliability in Electronics; Statler Hotel, New York. Sponsored by IRE professional group on quality control and electronic technical committee of ASQC, meeting will include discussion of relation between quality control and reliability, techniques in manufacturing and engineering, military and airborne reliability.

December 8–10: Eastern Joint Computer Conference and Exhibition; Bellevue-Stratford Hotel, Philadelphia, Pa. This meeting devoted to design and application of small digital computers is jointly sponsored by American Institute of Electrical Engineers, Institute of Radio Engineers, and the Association for Computing Machinery. Proceedings will be published by the sponsors. Over 60 companies will exhibit products. Information is obtainable from EJCC, Box 7825, Philadelphia 1, Pa.

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A top team of scientists, physicists and engineers is being assembled at Martin to carry on a planned, long-range program of development in the tremendous new science of nuclear power.

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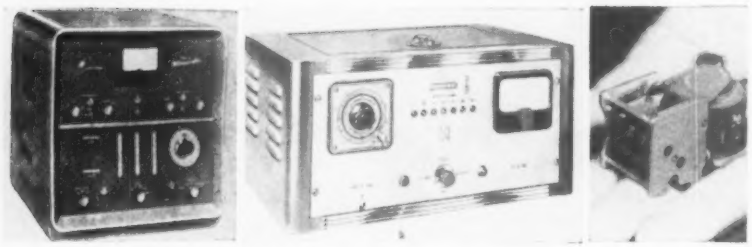
PRODUCTS AND MATERIALS



Scaling Equipment and Components

Three scalers—model 192 decade (above, left), model S-1500 scale-of-128 (above, center), and model A-65 scale-of-64—and five counting components are available.

Model 192 permits manual or preset time or count (10, 100, or 1,000 × scaling factor) operation. Unit provides 500–2,500 volts for counters. Input sensitivities are 1–800 mv with 0.25-volt G-M counter position. *Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.* (P-1)

Model S-1500 gives linear amplification from 1 mv to 1 volt; sensitivity is 2 mv. Discriminator accepts 2–120 volt pulses. Regulated supply is 700–2,000 volts. *Nuclear Research and Development, Inc., 6425 Etzel Ave., St. Louis 14, Mo.* (P-2)

Model A-65, 6-digit register, has 0.25-volt input sensitivity; resolution of interchangeable scaling stages is <5 μsec. *The Atomic Center for Instruments and Equipment, Inc., 489 Fifth Ave., New York 17, N. Y.* (P-3)

Additive or subtractive magnetic counter (above, right), manually reset, displays 3 or 4 digits at 1,200 cpm, max.; it is wound for 6–110 volts, d-c. *Abrams Instrument Corp., 606 E. Shiawassee St., Lansing 1, Mich.* (P-4)

Model MC-504 SZL magnetic 4-digit counter subtracts from 999.9 to 000.0, operates microswitch at zero level; wheels are individually set. *Photocon Research Products, 421 N. Foothill Blvd., Pasadena 8, Calif.* (P-5)

Types 100A and 100B direct-reading plug-in decimal counters produce output pulse and reset on tenth input pulse. Inputs are 0–40 and 0–100 kc; resolution, 5 μsec; signal, 100 volts. *Advance Electronics Co., Inc., 451 Highland Ave., Passaic, N. J.* (P-6)

Type M2923 ternary counter has three sequentially operating stable states; it saves space and power compared to ring or binary counters. Frequency is 0–100 kc; required input, 60–150 volts and 0.5–1.5 μsec risetime. *The Walkirt Co., 145 W. Hazel St., Inglewood, Calif.* (P-7)

Dekatron GC-10D scale-of-10 cold-cathode counting tube, with maximum 20,000-cps input, operates on 420 volts, d-c, with 800-μa anode current. *Ericcson Telephones Ltd. (distributor: Atomic Instrument Co., 84 Massachusetts Ave., Cambridge, Mass.).* (P-8)

RADIATION DETECTORS AND ACCESSORIES

Scintillation Survey Meter

The 53-lb battery-operated "Ferret" scintillation survey meter is designed for aerial and ground-vehicle prospecting. Two-in.-diameter, 2-in.-thick γ-sensitive crystal is optically connected to photomultiplier. Counting-rate meter has six sensitivity ranges and four variable time constants. Lead shielding provides directionality. *The Radiac Co., Inc., 489 Fifth Ave., New York 17, N. Y.* (P-9)

COUNTING-SHIELD ASSEMBLY. Model 14L 2-in.-thick lead shield parts can be assembled for scintillation well counting or standard counting methods with end-window scintillation and G-M counters. *R-C Scientific Instrument Co., Inc., 307 Culver Blvd., Playa del Rey, Calif.* (P-10)

ALPHA SCINTILLATION COUNTER. Model DPl alpha scintillation counter contains 6292 photomultiplier, ZnS phosphor, and preamplifier in lightproof housing. *Detectolab, Inc., 6544 Sheridan Rd., Chicago 26, Ill.* (P-11)

ELECTRONIC TIMER. Type 12 MC timer, using cold-cathode tubes, provides 0.05–7 sec intervals; output feeds into single-pole, double-throw, normally open relay. *G. C. Wilson and Co., 1950 Eighth Ave., Huntington, W. Va.* (P-12)

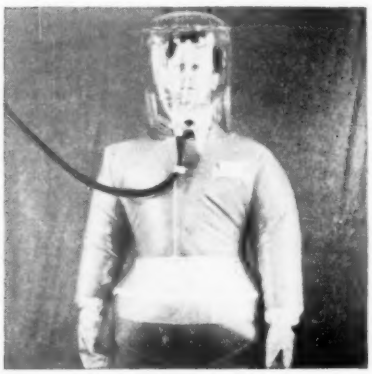
PHOSPHORS. NE201 liquid phosphor is sealed in glass cells, 1½–16 in. diameter and 1½–16 in. length; NE101 plastic phosphor (carbon 91%, hydrogen 9%) has 1–10 in. diameter. Compared with anthracene crystal: counting rates are 95% and 90%, pulse heights 75% and 50%, decay constants 2×10^{-9} and 4.0×10^{-9} sec, respectively. *Nuclear Enterprises Ltd., 1124 Grosvenor Ave., Winnipeg, Can.* (P-13)

CONVERTER. Models 5 MVT and 10 MVT 3-oz converters deliver 0–7,000 volts with 1 or 2 dry cells or on a-c; regulation is 2% or better with suggested stabilizer circuits. *Precise Measurements Co., 942 Kings Highway, Brooklyn 23, N. Y.* (P-14)

AMPLIFYING CIRCUIT. AlC amplifier and preamplifier are improved modifications of ORNL circuits; preamplifier provides negative supply for photomultipliers. Negative pulse-height selector output is ≥20-volt amplitude. *Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.* (P-15)

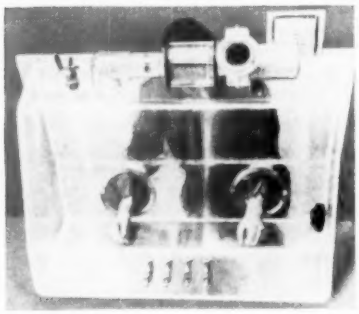
RADIATION MONITOR. Type 104 2-lb 12-oz G-M monitor uses transistor circuit to convert 30-volt hearing-aid-battery supply to 400-volt tube potential; indication is audio. *Radiometrics Ltd., 44, Tottenham Court Rd., London W1, England.* (P-16)

RADIOACTIVITY MATERIALS, APPARATUS



Protective Clothing

Used at British atomic energy installations, this suit literally envelopes the wearer in a plastic balloon. Excess pressure of ½ psi supplied via hose keeps contaminated air out. Air escapes through valve in back; circulation of air prevents misting of visor. Made of polyvinylchloride sheet, the suit is in two parts sealed together at the waist with a 2-in.-wide strip of cellophane tape. *Plysu Products Ltd., Woburn Sands, Bletchley, Buckminster, England.* (P-17)



New Dry Box

This one-piece dry box with no sharp corners is molded of heat- and chemical-resistant transparent plastic. Equipped with air filter for dust larger than 1 micron; electronic controls maintain humidity to 1%. Can be hermetically sealed in 30 sec. Inexpensive box can be discarded if contaminated. *P. M. Lennard Co., Inc., 671 Bergen St., Brooklyn 38, N. Y.* (P-18)

OXYGEN-18. Up to 30% O^{18} available in mass spectrometer-analyzed, labeled water. *Dajac Laboratories Division of Monomer-Polymer, Inc., Leominster, Mass.* (P-19)

LABELED AMINO ACIDS. Millicurie units of *dl*-norvaline 1-C^{14}, *dl*-norvaline 2-C^{14}, and *dl*-norleucine 2-C^{14} are available. *Bio-Rad Laboratories, 800 Delaware St., Berkeley, Cal.* (P-20)

LAB APPARATUS, MATERIALS

Magnetic Stirrers

Heavy duty $\frac{1}{30}$-hp induction motor drives 3-in³ Alnico 5 magnet of model 10244 magnetic stirrer. Stirrer has stepless speed control, pilot light and Teflon-covered bar. Case is 12 in. in diameter. *Wilkens-Anderson Co., 4525 W. Division St., Chicago 51, Ill.* (P-21)

Simultaneous heating and stirring can be done with king-size Magne-Stir stirrer. Built-in hot plate supplies heat. Rheostat control varies speed. *Labline, Inc., 217 N. Desplaines St., Chicago 51, Ill.* (P-22)

Low-Temperature Bath

Control from −5 to 65° C ± 0.01° C is claimed by the manufacturer for No. 882 refrigerated visibility bath. Compact, portable unit offers full visibility and unobstructed working space. Mechanical refrigeration unit and 300-watt heating element provide temperature adjustment. Mercury thermoregulator and thyratron tube relay control their operation. *Wilkens-Anderson Co., 4525 W. Division St., Chicago 51, Ill.* (P-23)

PORTABLE REFRIGERATION UNIT. Sealed compressor, ⅛ hp, delivers 790 Btu at 20° F. Thermostat maintains temperature control with 1–2° differential. Cooling coil is 8 × 5 in. *A. Daigger and Co., 159 W. Kinzie St., Chicago 10, Ill.* (P-24)

TEMPERATURE BATH. General laboratory or serological work can be done using Sero-Utility bath. Of stainless steel construction, bath operates to 100° C, with accuracy of 0.03° C. Depth can easily be changed from 7 to 5 in. by removing shelf's legs. *Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.* (P-25)

BATCH OVENS. Air recirculation system is said to maintain uniform temperature throughout work chamber of models HB, HA and V laboratory ovens. Ovens are either gas- or electric-fired. Units feature adjustable air volume. *Burdett Mfg. Co., 3433 W. Madison St., Chicago 24, Ill.* (P-26)

SHAKER. Speed control and timer are features of multipurpose shaker for laboratory glassware. *Palo Laboratory Supplies Co., 81 Reade St., New York 7, N. Y.* (P-27)

Products Index

To facilitate your finding the products of greatest interest to you, the "Products and Materials" department, starting with this issue, will be categorized and indexed.

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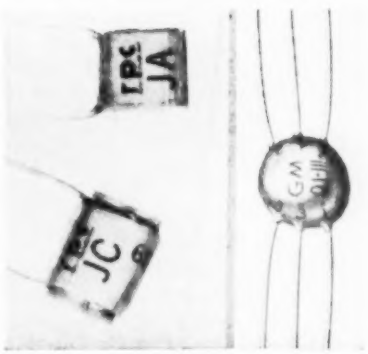
CIRCUIT COMPONENTS



Miniature Components

More and more circuits are going miniature; midget components and printed circuitry for this trend are featured here.

The Acepot is a precision 2-watt wire-wound potentiometer only ½ in. in diameter and 1 in. long. Resistance range is 200–50,000 ohms, ±2%;

linearity, 0.3%; weight, 0.25 oz. *Ace Electronics Associates, Potentiometer Division, 125–129 Rogers Avenue, Somerville 44, Mass.* (P-28)

Type JA subminiature precision wire-wound resistors (p. 83, left) are $\frac{1}{4}$ in. in diameter by $\frac{1}{4}$ in. long, max. resistance is 125,000 ohms, 0.1 watt. Type JC is $\frac{3}{8}$ in. long, max. resistance 250,000 ohms, 0.15 watt. Both feature low temperature coefficient of resistance. Special models are available. *Resistance Products Co., 714 Race St., Harrisburg, Pa.* (P-29)

Toroidal-steel-core pulse transformers (p. 83, right) have 1:1 turns ratio, are $\frac{3}{8} \times \frac{3}{8} \times 2\frac{3}{8}$ in., and can produce 0.05–2 μsec duration pulses in a blocking oscillator. Rise time is less than 0.005 μsec for 0.1 μsec unit. *Gudeman Co., 340 W. Huron St., Chicago 10, Ill.* (P-30)

Panel-mounting subminiature toggle switches are available with three different combinations of detented (maintained) or spring-loaded (momentary) positions. Consisting of two SPDT units, the switches can control as many as four circuits. Rating is 5 amp at 250 v a-c. *Micro Switch Division of Minneapolis-Honeywell Regulator Co., Freeport, Ill.* (P-31)

The 831 Basic Laboratory Kit contains six conductive silver paints, six resistive coatings, accessory chemicals and a manual for printed circuit research. *Micro-Circuits Co., New Buffalo, Mich.* (P-32)

Series 3370 and 3371 printed circuit card receptacles offer up to 15 contacts and pressure type and solder dip assembly respectively. Type 3366 right-angle terminal strip makes assembly of printed circuit cards easy through use of the fast-dip method of solder points. *H. H. Buggie, Inc., 726 Stanton St., Toledo 4, Ohio.* (P-33)

Carbon Trimpot is a linear potentiometer only $\frac{1}{4} \times \frac{5}{16} \times 1\frac{1}{4}$ in. with resistances from 0.02–1 megohm. Dual output Twinpots also available, as are Liniometers for transducing linear displacement. *Bourns Laboratories, 6135 Magnolia Ave., Riverside, Cal.* (P-34)

Type C-5 miniature resistors are 0.032 in. in diameter by $\frac{9}{32}$ in. long. Power rating is $\frac{1}{8}$ watt; resistance, 5 to 500,000 ohms. *Mepco Inc., 37 Abbett Ave., Morristown, N. J.* (P-35)

Though only $\frac{1}{8} \times \frac{3}{4} \times \frac{11}{32}$ in. excluding pins, the 4-contact G-20 miniaturized connector will withstand 3,500 volts. Available with 2 and 3 contacts. *DeJur-Amsco Corp., 45–01 Northern Blvd., L. I. City, N. Y.* (P-36)

COMPONENTS IN BRIEF

THYRATRONS. The AX-5544 and AX-5545 are three electrode, xenon filled, RETMA types. Type AX-5727 is a ruggedized version of the 2D21. *Amperex Electronic Corp., 230 Duffy Ave., Hicksville, L. I., N. Y.* (P-37)

PENTODE. Similar to the 6AH6, the new miniature CK6485 pentode offers high g_m and good figure of merit. *Raytheon Mfg. Co., 55 Chapel St., Newton 58, Mass.* (P-38)

TRIODE. Type 6337 features high plate dissipation and high perveance for regulating circuits. *Chatham Electronics Corp., Livingston, N. J.* (P-39)

SELENIUM DIODES. Subminiature types deliver up to 11 ma at 80 v. Complete encapsulation permits operation over extended temperature range. *International Rectifier Corp., El Segundo, Cal.* (P-40)

GERMANIUM DIODES. Type 1N, available in 19 ratings, comes in functional hexagonal body tapered to indicate direction of current flow. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.* (P-41)

THYRATRON. Type 6478 xenon thyratron offers plate current of 1.5 amp (20 amp peak), 80 μsec deionization, small size. *Taylor Tubes, Inc., 2312 Wabansia Ave., Chicago 47, Ill.* (P-42)

TRIMMER POTENTIOMETERS. Metal-film trimmer potentiometers cover 1% of their range per 90 deg rotation of the adjustment screw. Available from 50 to 25,000 ohms, $\frac{1}{2}$ w, ±10% tolerance, ±5% linearity. *Technology Instrument Corp., Acton, Mass.* (P-43)

TERMINAL BOARDS. Class STB boards are available with 4, 12, 16, and 20 studs. Other molded terminal blocks, space-saving outlets, and toggle switches are offered. *Kulka Mfg. Co., Inc., Mt. Vernon, N. Y.* (P-44)

TERMINALS. Variety of silver-plated brass terminals are offered. *Tangas Mfg. Co., Inc., Delavan, Wis.* (P-45)

SMALL CONNECTORS. K-Miniature series offers a complete connector line with aluminum alloy shells and nylon inserts having 10, 20, or 30 contacts. *Cannon Electric Co., 3209 Humboldt St., Los Angeles 31, Cal.* (P-46)

SOLDERLESS TERMINALS. Faston line of push-on connectors has been extended to include types designed for 18–22 gage wire and for hand tool or automatic machine application. *Aircraft-Marine Products, Inc., 2100 Paxton St., Harrisburg, Pa.* (P-47)

VERTICAL-MOUNTING RELAY. Fitting the standard octal socket, DPDT relay has 3 amp contact capacity, 0.1 w d-c consumption. *Hedin Tele-Technical Corp., Livingston, N. J.* (P-48)

PLATE RELAYS. Drop-out currents only 1% below pull-in are possible with the new RL-516 SPDT relay. Other types with more contacts and sensitivities to 80 mw are available. *Joseph Pollack Corp., 81 Freeport St., Boston 22, Mass.* (P-49)

IRON CORES. Standardized "preferred type" powdered iron cores that meet 8 out of 10 applications are available from stock. *Electronic Components Division, Stackpole Carbon Co., St. Marys, Pa.* (P-50)

RESIN SOLVENT. Reclaiming potted equipment is made simple by De-Solv 292, which disintegrates epoxy or polyester resins without damaging other circuit materials, even phenolic printed circuits. *RAM Chemicals, 200 E. Olive St., Gardenia, Cal.* (P-51)

THREE-TURN POTENTIOMETER. Series 930 micropots permit use of either or both mechanical stops as phasing points; one to five gang models available, single or double shaft. *George W. Borg Corp., Jamesville, Wis.* (P-52)

UHF ATTENUATOR. Flat frequency response from 0 to 10 Mc, 75 ohm impedance ±2½%, and convenient size make the V-250 variable attenuator useful in pulse work. *Daven Co., 191 Central Ave., Newark, N. J.* (P-53)

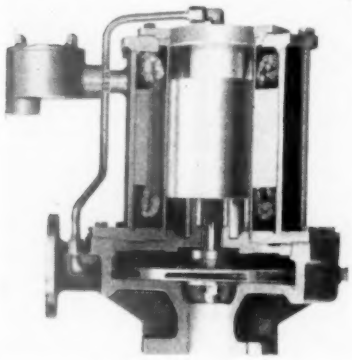
MULTI-TURN POTENTIOMETER. Servo-controlled winding gives the type M10T 0.05% linearity; 3,600-deg rotation provides high resolution; sturdiness insures reliability. *Technology Instrument Corp., Acton, Mass.* (P-54)

PUMPS, VALVES, AND SEALS

Compact Solenoid Valve

Asco two-way packless solenoid valves control flow of gas, water, light oil, and other noncorrosive fluids. Normally-closed valve measures $3\frac{13}{16}$ in. high and $2\frac{3}{4}$ in. face-to-face (also avail-

able normally open). Used with pipe sizes of $^3/_8$, $^1/_2$, $^3/_4$, and 1 in., valves can be operated with standard a-c or d-c voltages; power consumption is 10 watts. Class A coils are standard, but others are available. *Automatic Switch Co., 391 Lakeside Ave., Orange, N. J.* (P-55)



Canned-Rotor Pump

Chempumps, with motor and pump combined in one rotor-impeller unit having no mechanical seals, stuffing boxes, or packing glands, are claimed to eliminate 90% of centrifugal pump maintenance problems. The pumps mount in the fluid line in any position. Standard Chempumps are available in cast iron, stainless steel, and Monel; sizes range from $^1/_8$ to 3 hp with capacities up to 180 gal/min at heads up to 90 ft; fluids can be handled to 450° F and 150 lb/in.^{2} Simple modifications permit use at 600° F, 5,000 lb/in.^{2} Special models are available. *Chempump Corp., 1300 E. Mermaid La., Philadelphia 18, Pa.* (P-56)

Two Series of Bellows Valves

Clifford Mfg. Co.'s packless valves are designed to provide a leaktight seal with minimum wear and deterioration. Manual or pneumatic-hydraulic models are available. They are especially suitable for vacuum systems, but can be used with volatile and corrosive fluids. Standard models are rated to 150 lb/in^2 with temperatures from −65 to 250° F. Inlet and outlet fittings are $^1/_8$-in. female pipe tap. *Clifford Mfg. Co., 152 Grove St., Waltham 54, Mass.* (P-57)

Aveco bellows-seal Series-1206 valves are available in needle and globe models for vacuum or pressure service with liquid or vapor. The needle point provides minute throttling over 90% of valve capacity. All wetted parts are type 316 S.S., except bellows, which is of either type 321 or 347. Teflon shut-off disks permit operation to 450° F; but Monel valves can be used to 900°F. Valves can be furnished with diaphragm operators or electric motors for automatic operation. Series-1212 remote-control valve, designed for vacuum service with liquid or vapor, is air-actuated and spring closed. *Associated Valve & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.* (P-58)

QUICK-SEAL HOSE COUPLINGS. Titeflex quick-seal leakproof hose couplings with built-in single- or double-check valves are available in both standard and heavy-duty models for high-pressure heavy-flow applications. Couplings are available in sizes up to 12 in., with male or female pipe threads, expansion ring, or barb shank. *Titeflex, Inc., 500 Frelinghuysen Ave., Newark 5, N. J.* (P-59)

CHECK VALVES. Check valves available in sizes up to 2 in. are designed to prevent unintentional mixing of two gases in cross-connected lines. *Circle Seal Precision Valves, 2181 E. Foothill Blvd., Pasadena 8, Calif.* (P-60)

MATERIALS

Foam-in-Place Plastic

Liquid Eccofoam-FP expands when catalyst is added and cures to a rigid thermosetting foam. Room-temperature process yields controllable 2–26-lb/ft^{3}densities. Properties of 10-lb/ft^3 foam are: 340-lb/in^2 compressive strength, 11,000-lb/in^2 modulus of elasticity, 1.18 dielectric constant, 0.0004 dissipation factor. *Emerson & Cuming, Inc., 869 Washington St., Canton, Mass.* (P-61)

PLASTIC BONDING MATERIAL. Tygoweld, an organic developed to weld metal to metal, metal to porcelain, and metal to glass, also can be used with other materials. Available in rod, powder, or paste, the material resists corrosion by oils, fats, and acids. *U. S. Stoneware Co., Akron, O.* (P-62)

FLUSHING OIL. Hyvac Flushing Oil for mechanical vacuum pumps is said to avoid contamination from detergents or volatile additives. It removes old oil, sediment, and dirt from vacuum pumps' internal mechanisms. *Central Scientific Co., 1700 Irving Park Rd., Chicago, Ill.* (P-63)

INSULATING COMPOUND. Quick-drying E-33 dipping compound for tools and equipment is said to be tough, chemically inert, and not damaged by greases or ordinary acids or alkalis. Dielectric strength is 1,200–1,500 volts/mil. *Insl-X Sales Co., 26 Rittenhouse Sq., Ardmore, Pa.* (P-64)

CAST-IRON WELDING ROD. Copper-coated cast-iron rod is designed to give machinable, blow-hole-free torch welds of 48,000-lb/in^2 tensile strength. Working temperature is 1,400° F. *All-State Welding Alloys Co., Inc., 249–55 Ferris Ave., White Plains, N. Y.* (P-65)

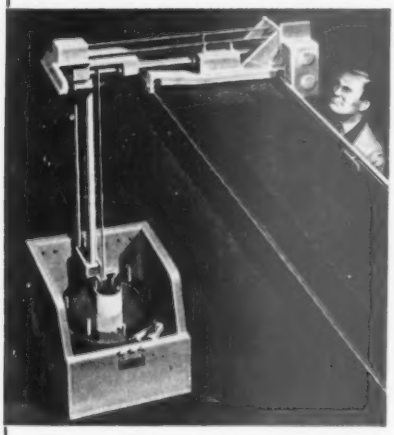
RUST PREVENTIVE. FerRoSeal, a liquid, chemically converts rust into a protective iron-phosphate coating. *Municipal Steel Corp., Chemical Div., 1225 Broadway, N. Y. 1, N. Y.* (P-66)

HOT-PRESSED TUNGSTEN CARBIDES. Sinterforge-SF hot-pressed tungsten carbides are said to improve structure uniformity and diminish porosity of high-cobalt compositions where ordinary machining techniques "sweat out" binder. *Sintercast Corp. of America, 134 Woodworth Ave., Yonkers 2, N. Y.* (P-67)

POROUS CARBON. Extremely-fine-grain carbon that contains 75% air is available in blocks or sheets up to about 10 in. × 10 in. and thicknesses up to $1^1/_2$ in. *Stackpole Carbon Co., St. Marys, Pa.* (P-68)

STERILIZABLE POLYETHYLENE. Irratherm-101, made by irradiating polyethylene with high-voltage electrons, is insoluble and infusible and retains toughness, moisture resistance, and chemical inertness. It contains no residual radioactivity. Material can be heated to 350° F without melting; but prolonged heating causes excessive

CARBOLOY® HEVIMET
Gives 40% more gamma ray protection than lead



For any application requiring shielding against radioactivity, Carboloy Hevimet combines excellent machinability with maximum density and minimum space.

Hevimet has a density of 17.0 gm/cm^3 (lead is 11.4). It is dimensionally stable, nonporous and easily joined; has relatively high compressive and tensile strength.

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oxidation. *General Electric Co., Pittsfield, Mass.* (P-69)

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BERYLLIUM DETECTOR. Factory-air monitor continuously records beryllium concentration with spark spectrograph and d-c amplifier. Also applicable to Si, Pb, Zr, V, Cr, Cd, Te, Ge, Sb, and Mn. *Winston Electronics Ltd., 1 Park Road, Hampton Hill, Middlesex, England.* (P-70)

GROUND TESTER. Model G-5 Automatic Ground Control stops equipment whenever resistance to ground exceeds 5 ohms, to eliminate hazards from leakage voltages. Also available is Model F conductivity tester for go/no-go testing in the megohm region. *Hewson Co., 443 Broad St., Newark 2, N. J.* (P-71)

INDUSTRY NOTES

▶**Electro Nuclear Corp.,** Harvey Bldg., West Palm Beach, Fla., has been formed to manufacture low-priced lab equipment. First product is electrometer.

▶**Computer-Measurements Division, Detectron Corp.,** North Hollywood, Cal., will make radiation scalers, electronic frequency counters, and time interval instruments.

▶**Control Products Co., Inc.,** Nobles-town Rd., Oakdale, Pa., will design and manufacture automatic control systems.

▶**Battelle Memorial Institute,** Columbus 1, Ohio, a nonprofit foundation, has facilities available for catalysis and surface chemistry research.

▶**Atlantic Research Corp.,** Alexandria, Va., has new facilities for experimental research in chemistry, engineering and applied physics.

▶**Electronic Associates, Inc.,** Long Branch, N. J., has opened a computation center, where problem analysis equipment and manpower can be rented.

▶**Plax Corp.,** Hartford, Conn., has sold its plastics rod, tube and sheet business to **Westlake Plastics Co.,** Lenni Mills, Pa.

LITERATURE AVAILABLE

Hand tachometers. Bulletin 103 describes three-range tachometers. 4p. *Metron Instrument Co., 432 Lincoln St., Denver, Col.* (L-1)

Steam-water cycle deposits. Bulletin 28X8155 gives information on mineral deposits. 3p. *Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.* (L-2)

Beryllium-copper strip. Technical data sheet 300 gives strip properties and working procedures. 4p. *American Silver Co., Inc., 36-07 Prince St., Flushing 54, N. Y.* (L-3)

Miniature connectors. Sheets give characteristics of rectangular G-20, hexagonal HC-20 and high voltage FHL-6 models. *DeJur Amsco Corp., 45-01 Northern Blvd., Long Island City 1, N. Y.* (L-4)

Hermetic terminals. Leaflet 5410 lists dimensions and properties of ceramic sealed terminals. 4p. *American Lava Corp., Chattanooga 5, Tenn.* (L-5)

Laboratory apparatus. Leaflet describes chemical and biological laboratory devices. *A. S. Aloe Co., 5655 Kingsbury, St. Louis 12, Mo.* (L-6)

Brazing manual. Booklet covers practical aspects of brazing various shapes and alloys. 24p. *All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y.* (L-7)

Pipe markers. Bulletin 135-B lists markers available. 4p. *W. H. Brady Co., 727 W. Glendale Ave., Milwaukee 12, Wis.* (L-8)

Demineralizer. Bulletin 128 describes small pressure water demineralizer. 2p. *Barnstead Still and Sterilizer Co., 222 Lanesville Terrace, Forest Hills, Boston 31, Mass.* (L-9)

Vibration monitor. Brochure 500-1 tells uses and specifications of vibration-responsive device. 4p. *The Beta Corp., P. O. Box 8625, Richmond 26, Va.* (L-10)

***p*H control.** Bulletin Q1304 shows complete *p*H recording and controlling systems. 38p. *The Bristol Co., Waterbury 20, Conn.* (L-11)

Miniature motor, generator. Leaflets SR-43 and GPM-44A describe 25-watt motor and 9-oz generator, respectively. 2p. apiece. *Dalmotor Co. 1356 Clay St., Santa Clara, Cal.* (L-12)

Platinum cladding. Leaflet tells applications of platinum cladding. 4p. *Baker and Co., 113 Astor St., Newark 5, N. J.* (L-13)

Thermocouple standards. Tentative "Temperature-EMF Relation for Iron-Constantan Thermocouples" are available. 14p. *Scientific Apparatus Mak-*

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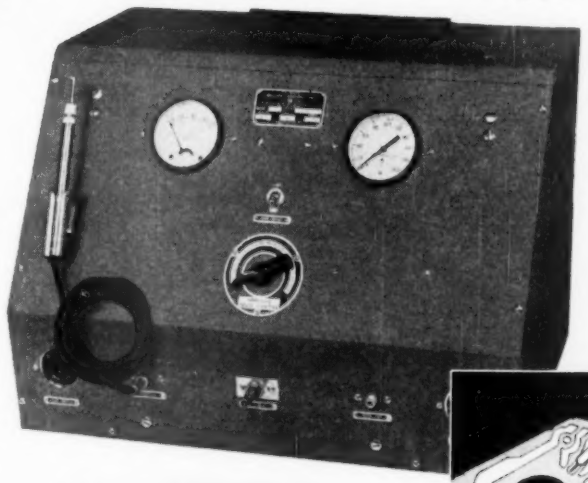

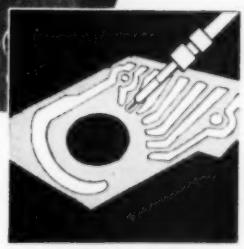

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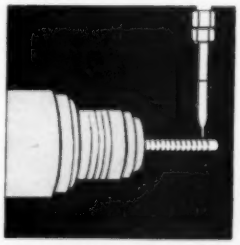

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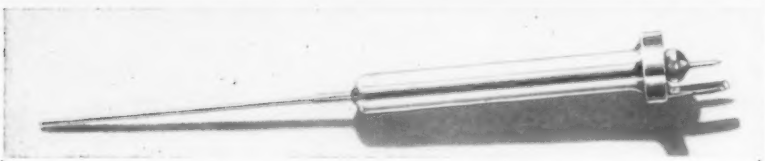

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H. W. LEIGHTON LABORATORIES, 26 Herman St., Glen Ridge, N. J.

ers Association, 522 5th Ave., New York 36, N. Y. (L-14)

X-Ray accessories. Catalog describes complete line of accessory and protection equipment. 56p. *Bar-Ray Products, Inc., 209 25th St., Brooklyn 32, N. Y.* (L-15)

Vibration meter. Bulletin CEC-1505C explains meter for oscillation studies. 4p. *Consolidated Engineering Corp., 300 Sierra Madre Ville, Pasadena 15, Cal.* (L-16)

Laboratory wares. Catalog listing line of apparatus is available. 16p. *Scientific Glass Apparatus Co., Inc., 100 Lakewood Terrace, Bloomfield, N. J.* (L-17)

Electrical instruments. Booklets describing line of instruments and differential transformers (Catalog AA-1) are available. 8 and 9p., respectively. *Schaevitz Engineering, P. O. Box 505, Camden 1, N. J.* (L-18)

Generators and power supplies. Catalog describes line of generators, power supplies, etc. 16p. *Communication Measurements Laboratory Inc., 350 Leland Ave., Plainfield, N. J.* (L-19)

Master-slave manipulator. Sheet describes remote handling unit, Model 8. *Central Research Laboratories, Inc., Red Wing, Minn.* (L-20)

Incubators. Section 2, catalog 100 details incubators and paraffin embedding ovens. 8p. *Chicago Surgical and Electrical Co., 217 N. Desplaines St., Chicago 6, Ill.* (L-21)

Miniature equipment. Bulletin 254 describes motors, blowers, etc. *Mission-Western Engineers, Inc., 132 W. Colorado St., Pasadena 1, Cal.* (L-22)

Selenium rectifiers. Bulletin 554 discusses rectifier applications. *Crown Chemical and Engineering Co., 4722 Worth St., Los Angeles 63, Cal.* (L-23)

Water conditioning. Bulletins 4505-A and 4643 describe small zeolite softener and deaerator, respectively. *Cochrane Corp., Philadelphia 32, Pa.* (L-24)

Special glassware. Catalog CA-1 lists custom-made laboratory apparatus. *Corning Glass Works, Corning, N. Y.* (L-25)

Filter presses. Catalog and specification book is available. *D. R. Sperry and Co., Batavia, Ill.* (L-26)

Plastics specifications. Chart gives government specifications for thermosetting laminated plastics. 1p. *Synthane Corp., Oaks, Pa.* (L-27)

Test chamber. Brochure gives characteristics of temperature test chamber. 4p. *Statham Development Corp., 12411 W. Olympic Blvd., Los Angeles 64, Cal.* (L-28)

Air-data computer. Brochure describes data computer. 8p. *Servomechanisms Inc., 500 Franklin Ave., Garden City, L. I., New York.* (L-29)

Indicating amplifier. Bulletin IA describes microvoltmeter, amplifier. 2p. *Doelcam Corp., 1400 Soldiers Field Rd., Boston 35, Mass.* (L-30)

Gas analyzers. Leaflet describes line of gas analyzers, based on conductivity measurements. 4p. *Charles Engelhard, Inc., 850 Passaic Ave., East Newark, N. J.* (L-31)

Precision cams. Bulletin discusses line of available cams. 4p. *Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N. Y.* (L-32)

Fuses. Catalog illustrates line of fuses that light when blown. 12p. *Sightmaster Corp., 111 Cedar St., New Rochelle, N. Y.* (L-33)

Miniature wire. Catalog discusses line of miniature wire and cable. 34p. *Tensolite Insulated Wire Co., Inc., Tarrytown, N. Y.* (L-34)

Chemical feeder. Catalog 70-50 explains feeder for small quantities of liquids. 2p. *Fischer and Porter Co., Hatboro, Pa.* (L-35)

Instrument publication. "Laboratory Report" on instrumentation subjects, is available. 4p. *Technology Instrument Corp., Acton, Mass.* (L-36)

Stripping solutions. Sheet describes wire-stripping solutions, for removing insulations. 1p. *Fidelity Chemical Products Corp., 470-474 Frelinghuysen Ave., Newark, N. J.* (L-37)

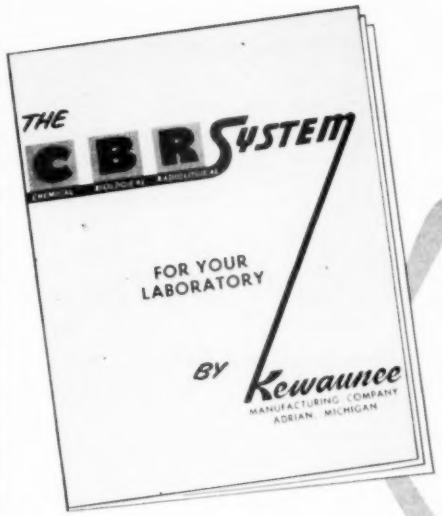
Ceramics. Chart gives electrical and mechanical properties of ceramics. 4p. *Frenchtown Porcelain Co., 89 Muirhead Ave., Trenton 9, N. J.* (L-38)

Materials handling. Booklet explains ideas for labor, space and equipment savings. *Factory Service Co., 4615 N. 21st St., Milwaukee 9, Wis.* (L-39)

Fast-setting cement. Sheet describes fast-setting cement for anchoring machinery. 1p. *Garon Products Co., 37 S. 13th St., Philadelphia 7, Pa.* (L-40)

Electrical ceramics. Chart gives electrical and mechanical properties of ceramics. 4p. *General Ceramics Corp., Keasbey, N. J.* (L-41)

Blind and plug valves. Catalog de-



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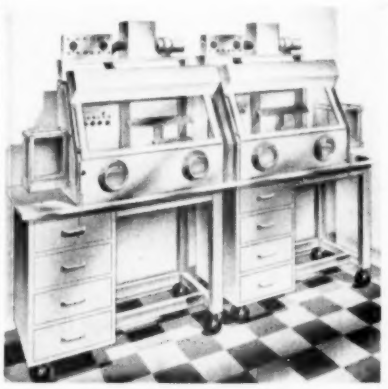

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scribes array of blind; plug valves. 74p. *Hamer Oil Tool Co., 2919 Gardenia Ave., Long Beach 6, Cal.* (L-42)

Electronic instruments. Catalog describes line of electronic test instruments. *Hewlett-Packard Co., 3000 Page Mill Rd., Palo Alto, Cal.* (L-43)

Servo potentiometers. Technical paper 341 discusses precision servo computer potentiometers. 12p. *Helipot Corp., 916 Meridian Ave., South Pasadena, Cal.* (L-44)

Resistors. Form S-074A lists data for resistor line. Bulletin T-1 gives characteristics of strip and disc resistors. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.* (L-45)

Germanium diodes. Bulletin GD-1A lists diode characteristics. 4p. *International Rectifier Corp., 1521 E. Grand Ave., El Segundo, Cal.* (L-46)

Colloidal dispersions. Bulletin 460 lists data for line of colloidal dispersions. 8p. *Acheson Colloids Co., Port Huron, Mich.* (L-47)

Liquid level gages and valves. Catalog 236 presents data on line of gages and valves. 8p. *Jerguson Gage and Valve Co., 80 Fellsway, Somerville 45, Mass.* (L-48)

Periscopes. Bulletin 301 discusses industrial periscopes. 4p. *Kollmorgen Optical Corp., 347 King St., Northampton, Mass.* (L-49)

Bridges and ratio sets. Booklet E-53 describes line of instruments for resistance and conductance measurements. *Leeds and Northrup Co., 4934 Stenton Ave., Philadelphia, Pa.* (L-50)

Instrument motor. Leaflet SG15-1 describes geared motors. 4p. *Merkle-Korff Gear Co., 213 N. Morgan St., Chicago 7, Ill.* (L-51)

Gas analyzers. Data sheet 10.15-12 describes electro-conductivity gas analyzers. 2p. *Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.* (L-52)

Instrument gears. Catalog illustrates types of precision gears. *Micron Gear Mfg. Co., 102-38 Corona Ave., Corona 68, N. Y.* (L-53)

Coatings. Catalog describes line of abrasion and corrosion protective coatings. *Magic Chemical Co., 121 Crescent St., Brockton, Mass.* (L-54)

Thermostats. Bulletin describes small thermostats. 4p. *Mechanical Industries Production Co., 217 Ash St., Akron 8, Ohio.* (L-55)

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Paper electrophoresis. Form 4R-554 details electrophoresis system. 4p. *Specialized Instruments Corp., 668 O'Neill Ave., Belmont, Cal.* (L-56)

Transformers. Bulletin P354 describes variable transformers. *Superior Electric Co., Bristol, Conn.* (L-57)

Radiation instruments. Catalog N describes complete line of radiation measuring equipment. 40p. *Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.* (L-58)

Scintillation counter. Brochure describes prospecting equipment. 4p. *Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.* (L-59)

Magnetic-particle tester. Sheet explains operation of flux-particle tester. 1p. *North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.* (L-60)

Resistors. Bulletin L-33 gives properties of boron-carbon resistors. *Shallcross Mfg. Co., Collingdale, Pa.* (L-61)

Markers and labels. Brochure describes line of markers for pipes, containers, etc. 8p. *North Shore Nameplate, Inc., Bank of Manhattan Bldg., Bayside, L. I., N. Y.* (L-62)

Powder metallurgy and data sheets. Bulletin 1 and data sheets PMS-12A-R2, PMS-12-B-R2 give introduction to powder metallurgy and iron core characteristics, respectively. 4 and 2p. *The National Radiator Co., Johnstown, Pa.* (L-63)

Steam costs. Booklet presents automatic boiler installations. 16p. *Orr and Sembower, Inc., Morgantown Rd., Reading, Pa.* (L-64)

Infrared analyzer. Folder describes in-plant stream analyzer. *Perkin-Elmer Corp., Norwalk, Conn.* (L-65)

Solenoids. Bulletin SO-100-300 describes line of miniature d-c solenoids. 4p. *Joseph Pollak Corp., 81 Freeport St., Boston 22, Mass.* (L-66)

Ovens and baths. Catalog 331A and data sheet 11297 describe line of laboratory ovens and low temperature baths, respectively. *Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.* (L-67)

Thermistor temperature indicator. Form 196 illustrates temperature indicating instrument. 2p. *Beckman and Whitley, Inc., 974 E. San Carlos Ave., San Carlos, Cal.* (L-68)

Instruments publication. Monthly leaflet "The RCL Counter" is available. 4p. *Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.* (L-69)

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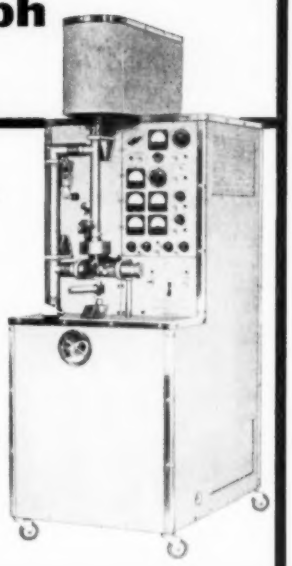

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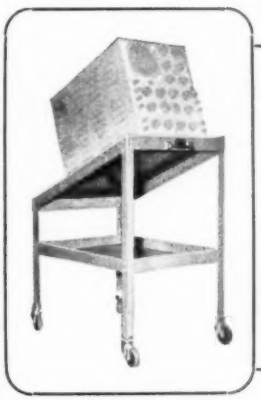

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(Classified Advertising)
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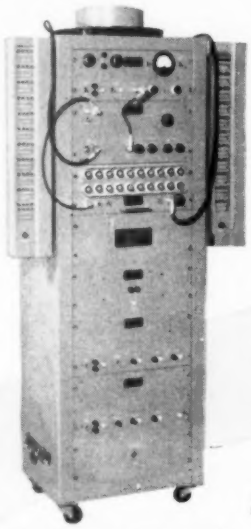

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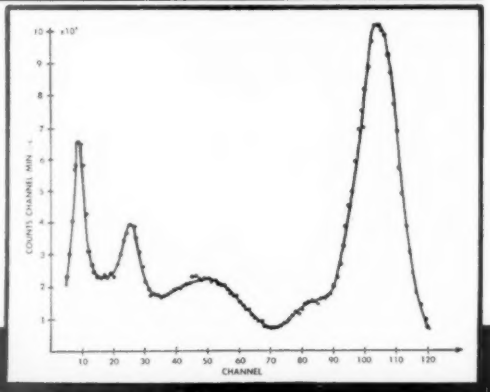
- All channels reset from one push-button control

A simplified analysis technique uses the Model 510 Single Channel Analyzer, a Model 218 Linear Amplifier, a Model 131 Scaler, and the related instruments described below.

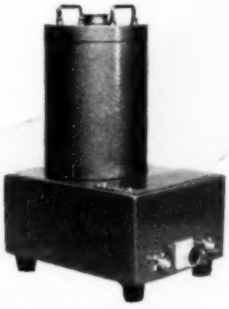


Gamma ray spectrum of I^{131}
A typical graph, obtained with the above instrument system, showing identifying characteristics of I^{131} radioisotope.
Charting time — 30 minutes.

Model 312

New STABLE (0.02% per day) Scintillation High Voltage Supply

- Exceptional high voltage stability practically eliminates drift for maximum accuracy (0.02% per day)
- Line regulation: 0.01% for line variation from 100 to 130 volts
- Either positive or negative output available through front panel switch
- Range: less than 200 volts to greater than 1400 volts in 17 steps



Model 810

New Bench-type WELL Scintillation Counter

- High linear response from built-in preamplifier
- Well-type Sodium Iodide Thallium Activated Crystal provides superior geometry for increased counting efficiency
- Specially designed for sample counting of gamma emitting radioisotopes
- Includes built-in lead shield to reduce background counting

For complete information on the Scintillation Spectrometry System, please request Bulletin 5202-1.

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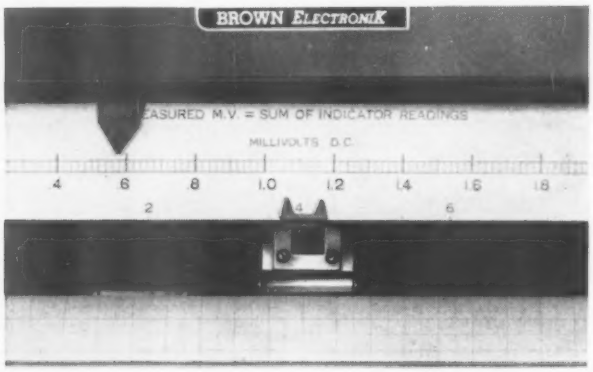
Now...the answer to high-resolution recording of test data

... *the* Extended Range *ElectroniK* Recorder



Closeup of indicating scale. Upper pointer shows millivolts within the span; lower pointer indicates millivolts to be added. Total reading: 4.58 mv.

DESIGNED especially for recording variables which change over a wide range, this new *ElectroniK* instrument records on a chart effectively *55 inches in width*. It has five equal measuring spans. Whenever the variable being measured reaches either the upper or lower limit of one of these ranges, the instrument automatically steps to the adjoining range and continues recording.

Two indicating pointers show the range in use and the value within the range. Connected to each pointer is a pen; one draws a purple record showing the range, the other draws a red record of the variable itself. To get the complete reading, you simply add both pen or pointer indications.

The complete range is 10.2 millivolts, in five 2-millivolt steps with an extra 0.2 millivolts on the high end of each span to provide an overlap that facilitates measurements near the change-over point. Pen speed of 4½ seconds full scale affords rapid response to quickly changing variables.

You'll find this new instrument particularly valuable in strain gage measurements and in dozens of other uses where high resolution aids interpretation of data. Your nearby Honeywell sales engineer will be glad to discuss your specific application . . . and he's as near as your phone.

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● **REFERENCE DATA:** Write for Data Sheet No. 10.0-18, "Extended Range Recorder."

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